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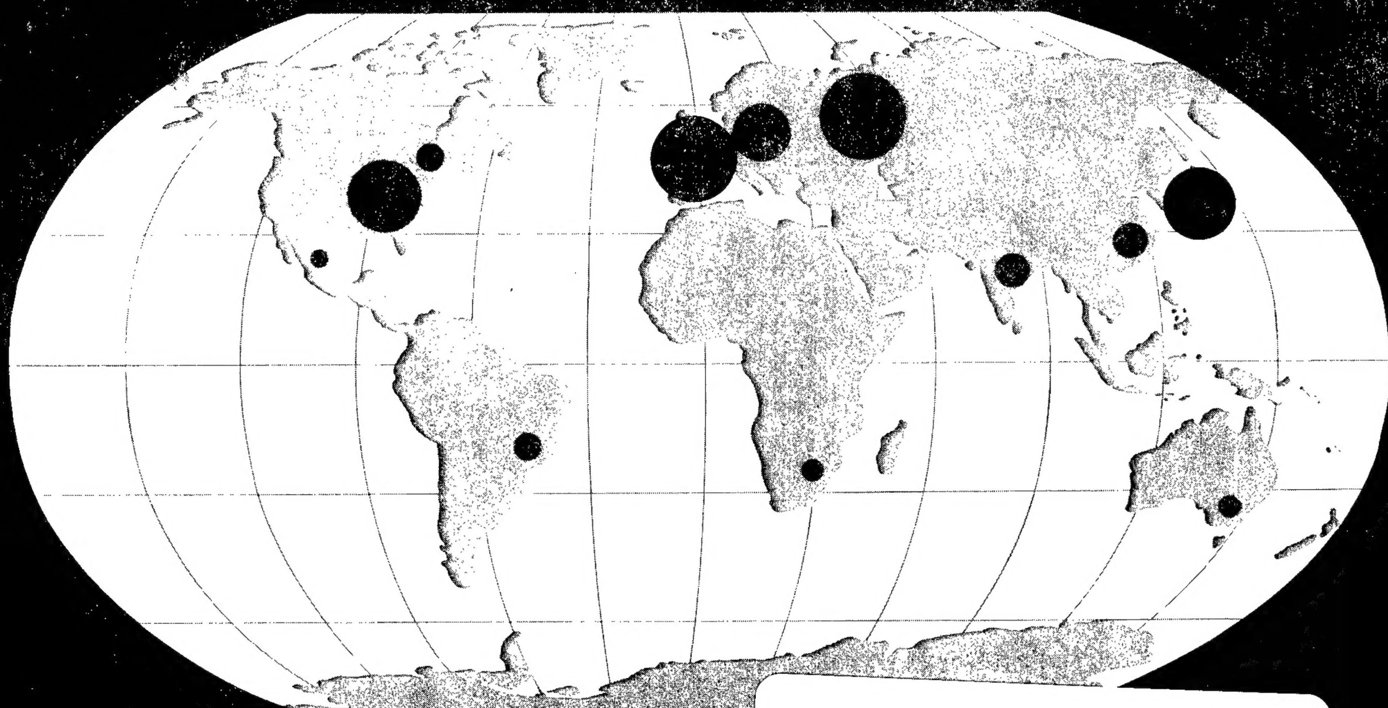
IRON AND STEEL



BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR

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Explanation of Cover

The circles and dots on the map on the cover are roughly proportional to the production of raw steel in various areas of the world as listed in table 1 of the text

IRON AND STEEL

MINERAL COMMODITY PROFILES
MCP-15, July 1978

This current report on iron and steel has been prepared by the Bureau of Mines, U.S. Department of the Interior to:

1. Provide the latest available data and information on iron and steel.
2. Invite comment, revisions, or additional information on the subject.

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IRON AND STEEL

By Donald H. Desy[1]

Iron and steel are the major metallic materials in use in the world today. The materials included in this general classification include rolled steel products, steel forgings, iron and steel castings, and smaller quantities of powder-metallurgical products. Iron and steel are used in virtually every phase of modern life, but the major uses are in transportation, construction, and machinery. The demand for iron and steel products in the United States was 126 million tons[2] in 1977, and it is expected to rise to 188 million tons in the year 2000. Transportation, construction, and machinery are expected to consume about 79 percent of this total. In the rest of the world, demand was 513 million tons in 1977, and it is expected to reach 1.17 billion tons in 2000.

Since 1959, the United States has changed from a net exporter to a net importer of steel, primarily because of the rise of Japan as a major steel producer and exporter, the rebuilding of the European steel industry after World War II, and the emergence of developing nations as steel producers. The resulting recent worldwide oversupply of steel, combined with the obsolescence of some portions of the U.S. steel industry, has led to increasing imports of steel into the United States. Even with rebuilding of some steel plants, extensions to existing plants, and construction of new ones, it is likely that imports will supply about a 15-percent share of the U.S. market in 2000. Iron and steel are expected to maintain their preeminent position among the metallic materials, although it is likely that aluminum, plastics, and possibly magnesium will find increasing use as substitutes, especially where weight saving is an important consideration.

INDUSTRY STRUCTURE

Background

The first use of iron is lost in antiquity. The remains of iron ornaments dating back to about 4000 B.C. have been found in Egypt, and pieces of iron have been found in the great pyramid at Giza dating from 2900 B.C. The first iron to be used was probably meteoric in origin, since pieces of iron meteorites can be hammered into useful shapes without the necessity of smelting. Iron was probably first obtained by smelting when a fire was built over an outcropping of ore; later primitive furnaces, or forges, were built. The iron age is usually dated as beginning about 1200 B.C. Written references to iron, as well as artifacts, have been found at the archeological sites of most ancient civilizations in the Middle East, as well as in India and China. Ironmaking was spread throughout Europe by the Romans, who learned the technology from the Greeks. By the time of the European discovery of America, iron was in widespread use in most of the rest of the world, but it was unknown in the Western Hemisphere.

Ironmaking in North America began during colonial times (*22*)[3]. Iron was produced in bloomery forges for local consumption beginning in the early 17th century. The first blast furnace works was built at Falling Creek, on the James River in Virginia, but it was destroyed in an Indian raid in 1622 before beginning production. The earliest blast furnace to produce iron in America was built in 1644 at Braintree (now West Quincy), Mass., but it was abandoned in 1647. The first furnace to operate successfully over a period of time was Hammersmith, built at what is now Saugus, Mass., in 1646, and it was operated until 1675. Later, ironworks were built in Maryland, Virginia, Massachusetts, Connecticut, and New Jersey. Most of the iron was consumed locally, but some was exported to England. By 1732, 16 blast furnaces and 19 hammer mills as well as numerous forges were operating in the American Colonies.

During the late 18th and early 19th centuries, ironmaking spread westward into Pennsylvania, Ohio, West Virginia, Indiana, and Illi-

[1] Physical scientist, Division of Ferrous Metals.
[2] Tons in this publication refer to short tons of 2,000 pounds.
[3] Italicized numbers in parentheses refer to items in the list of references at the end of this report.

nois. Blast furnaces became larger and, as supplies of charcoal became scarcer, anthracite, and later coke, were substituted for it. The introduction of hot blast around 1840 not only made the use of anthracite practical but also greatly improved the productivity of the blast furnace. Production of pig iron in anthracite blast furnaces increased rapidly in the United States, from approximately 22,000 tons in 1842 to 393,000 tons in 1856.

Wrought iron was made by refining pig iron in puddling furnaces in batches of about 500 pounds and was used for pipe and structural purposes. Steel was made by cementation, (the diffusion of carbon into solid wrought iron) or by the crucible process, in which wrought iron was melted together with carbon in clay or graphite crucibles holding about 100 pounds each. The medium- to high-carbon steel so produced was used for tools, implements, and machinery parts where greater hardness and strength were required than could be obtained from wrought iron.

The introduction of the Bessemer converter in the mid-19th century made the modern age of steel possible. Batches of up to 25 or more tons of molten pig iron could be converted into steel by blowing air through the metal to remove the excess carbon and other elements. The heat of combustion of these elements prevented the iron from cooling and solidifying. Bessemer steel could be made with any desired carbon content and was used in large quantities for railroad rails, construction, and shipbuilding. Although the pneumatic process for making steel was discovered independently in the United States by William Kelly in 1850 and by Henry Bessemer in England in 1856, the process was developed commercially by Bessemer and is now known by his name. An important part of the process, deoxidation by manganese, was developed by Robert Mushet. The basic lined, or Thomas, converter was later developed to utilize the high-phosphorus iron ores of Europe.

The Bessemer process was the dominant method of making steel in the United States from its inception up to the early 20th century. The Siemens-Martin, or open-hearth, process was invented in the 1860's, but did not become important until the late 19th and early 20th centuries. This process has the advantage of producing higher quality steel such as the grades used for deep-drawn automobile body parts, and it also is able to utilize a large proportion of scrap in its charge. Open-hearth production surpassed that of Bessemer steel by 1908, and by 1968 the Bessemer process had virtually disappeared.

Table 1.—World raw steel production 1977; and capacity, 1977 and 1980

(Million short tons)

	Production	Capacity	
	1977[p]	1977	1980
North America:			
United States	124.7	160.0	163.0
Canada	15.1	17.9	19.0
Mexico	[e]6.1	6.8	8.2
Other	[e]0.3	0.4	0.5
Total North America	146.2	185.1	190.7
South America	17.7	20.7	27.5
Europe:			
EEC	139.0	223.9	233.0
Other Western	32.1	36.6	41.4
U.S.S.R.	162.0	172.0	191.0
Other Eastern	64.2	69.0	80.0
Total Europe	397.3	501.5	545.4
Africa	[e]9.3	11.5	14.0
Oceania	[e]8.3	8.6	10.0
Asia:			
Japan	112.9	168.4	175.7
China, People's Republic of	[e]25.8	35.0	40.0
Other	24.4	26.5	32.5
Total Asia	163.1	229.9	248.2
World total	741.9	957.3	1,035.8

[e] Estimate.
[p] Preliminary.

The electric arc furnace process was first used for melting steel by William Siemens in England in 1880, and it was developed by Paul Héroult in France in the 1890's. The first electric arc steel furnace in the United States was built by Héroult in Syracuse, N.Y. in 1906. The electric arc furnace was first used for the production of alloy, stainless, and tool steels. During and after World War II, ordinary grades of steel were made in furnaces of larger capacity, and electric arc furnaces of up to 400 tons capacity are now operating. A relatively recent development is the "minimill," which uses the electric arc furnace to melt a scrap charge, generally employs continuous casting, and produces rolled products, mostly for local consumption.

The Linz-Donawitz (L-D) process for oxygen steelmaking was developed in Austria in 1952 and first brought to the United States in 1954. By 1965, this process, known in the United States as the basic oxygen process (BOP), accounted for 17 percent of U.S. raw steel production; in 1970, BOP production at 63 million tons, exceeded open-hearth production for the first time. In 1977, the BOP accounted for 62 percent of total U.S. raw steel production.

The blast furnace has shown continual increase in size and improvement in design and operation. Higher productivity has been achieved through the use of beneficiated and sized raw materials, higher blast temperatures,

Table 2.—U.S. production of pig iron, by State

(Thousand short tons)

State	1974	1975	1976	1977[p]
Alabama	3,874	3,624	3,297	3,014
Illinois	7,184	5,218	6,429	6,203
Indiana	17,001	15,657	17,439	16,492
Ohio	17,464	14,120	15,762	14,687
Pennsylvania	21,695	17,366	18,007	16,636
California, Colorado, Utah	5,094	4,568	4,694	4,733
Kentucky, Maryland, Texas, West Virginia	10,882	8,857	9,472	9,226
Michigan	7,612	7,012	7,386	6,817
New York	4,671	3,299	4,362	3,541
Total	95,477	79,721	86,848	81,349

[p] Preliminary.

Table 3.—U.S. production of raw steel, by State

(Thousand short tons)

State	1974	1975	1976	1977[p]
New York	5,495	3,401	4,799	4,075
Pennsylvania	33,535	25,761	26,696	25,742
Connecticut, Delaware, Maryland, New Jersey, Rhode Island	6,898	5,094	5,870	5,368
Florida, Georgia, Louisiana, North Carolina, South Carolina, Virginia, West Virginia	5,619	4,795	5,403	5,489
Kentucky	2,703	2,081	2,206	2,289
Alabama, Arkansas, Mississippi, Tennessee	4,767	4,308	4,109	3,959
Ohio	25,251	19,620	22,419	21,466
Indiana	23,088	19,807	22,178	21,469
Illinois	12,939	9,552	11,030	10,871
Michigan	10,459	9,093	10,382	10,030
Iowa, Minnesota, Missouri, Nebraska, Oklahoma, Texas	5,751	5,399	5,079	6,043
Arizona, Colorado, Hawaii, Oregon, Utah, Washington	4,922	4,380	4,431	4,695
California	4,293	3,351	3,398	3,248
Total	145,720	116,642	128,000	124,746

[p] Preliminary.

humidity control, high top pressure, and fuel and oxygen injection.

Recent developments in the steel industry include continuous casting, vacuum degassing, vacuum and electroslag remelting, and commercial development of direct reduced iron.

Size, Organization, and Geographic Distribution

The steel industry of the United States is composed of approximately 180 companies which produce a wide range of steel mill products; 86 have their own steelmaking furnaces, and the others purchase semifinished steel for fabrication into consumer goods. In 1977, 19 companies were fully integrated, operating blast furnaces, steelmaking furnaces, and finishing mills, and 40 companies operated 51 minimills. The term minimill has been defined as an electric arc furnace steelmaking plant which produces 600,000 tons or less of raw steel annually. Pig iron was produced by 21 companies from 174 blast furnaces standing as of January 1, 1978. In 1977, the industry had assets valued at $35.4 billion; it employed over 450,000 people, and it generated more than $39 billion in revenue.

The steel industry produces most of its own iron ore, coal, limestone, and dolomite and operates its own coking plants, which produce a wide range of byproducts. It produces about one-fourth of the power and some of the ferroalloys that it uses. Yet the steel industry buys essentially all of its fuel oil, natural gas, a large part of its fluorspar, and some metallurgical coke on the open market.

The foundry industry includes approximately 1,300 foundries producing gray, malleable, and ductile iron castings, and steel castings. The foundries range in size from small, two- or three-man operations to large, multimillion-dollar enterprises which may employ several thousand people.

The iron and steel scrap industry ranges in size from one-man collectors to multimillion-dollar brokerage or processing concerns with operations throughout the United States. Iron and steel scrap is produced by about 3,600 companies with approximately 37,000 employees. However, in 1977, 95 percent of the domestic scrap was handled by about 1,500 firms. Capital investment in this industry (replacement value of land, building, and equipment) is nearly $2 billion.

Most of the steel industry of the United States is located in the industrial complex surrounding the lower Great Lakes ports in Illinois, Indiana, Michigan, Ohio, and western Pennsylvania. There are large integrated steel mills in northern New York, eastern Pennsylvania, eastern Maryland, and the Birmingham district of Alabama, and relatively small integrated steelmaking plants in west-central Illi-

Table 4.—U.S. shipments of iron and steel castings by geographic area

(Thousand short tons)

Area	1974	1975	1976	1977[e]
New England	149	[1] 86	123	130
Middle Atlantic	3,642	2,820	[1] 2,771	2,890
East North Central	9,184	7,817	9,052	9,500
West North Central	951	[1] 742	[1] 756	790
South Atlantic	530	414	[1] 421	450
East South Central	2,459	[1] 1,831	[1] 2,027	2,140
West South Central	713	[1] 559	[1] 617	650
Mountain	387	338	[1] 372	400
Pacific	649	516	515	550
Total[2]	18,664	15,211	16,783	17,500

[e] Estimate.
[1] Excludes malleable iron castings.
[2] Data may not add to totals shown because of data withheld to avoid disclosing individual company figures.
Source: U.S. Department of Commerce, Bureau of the Census.

Table 5.—Specifications for various grades of pig iron

Grade	Chemical composition, percent			
	Silicon	Sulfur, maximum	Phosphorus	Manganese
Northern basic	1.50 Max	0.05	0.40 Max	1.01-2.00
Southern basic	1.50 Max	.05	.90 Max	0.40-0.75
Low Phosphorus	.50-3.00	.035	.035 Max	.75-1.25
Intermediate low phosphorus	1.00-3.00	.05	.036-.075	.75-1.25
Bessemer	1.00-3.00	.05	.076-.100	0-1.25
Malleable	.75-3.50	.05	.101-.30	.50-1.25
Foundry low phosphorus	1.75-3.50	.05	.31-.50	.50-1.25
Foundry intermediate phosphorus	1.75-3.50	.05	.51-.70	.50-1.25
Foundry high phosphorus	1.75-3.50	.05	.71-.90	.25-1.00
Silvery	5.0-17.0	.05	.30 Max	.50-2.00

Source: ASTM Spec. A43-75 Foundry Pig Iron, and AISI Steel Products Manual, Section 1, Pig Iron and Blast Furnace Alloys, 1951.

nois, Texas, Colorado, Utah, and California. The pattern of geographic distribution of the foundry industry in general follows that of the steel industry. The pattern of the iron and steel scrap industry is modified somewhat by the difference between areas of maximum production and areas of maximum consumption. Most scrap iron and steel is processed near where it is generated.

In the market economy countries, most steel is produced in the United States, in Western Europe, and in Japan. The U.S.S.R. has the largest steel industry of the centrally controlled economy countries. In addition, Poland, Czechoslovakia, Romania, and the People's Republic of China have substantial steel industries. There are significant steel industries in Canada, Argentina, Brazil, the Republic of South Africa, India, and Australia.

Definitions, Grades, Specifications

Pig iron is a high-carbon iron made by smelting iron ore in the blast furnace with carbonaceous material as a reducing agent, usually coke in current practice. *Hot metal* generally refers to molten pig iron. *Direct casting* pig iron is hot metal that is cast directly into useful shapes, such as ingot molds. *Silvery pig iron* is an intermediate product between pig iron and ferrosilicon and is included in the pig iron classification. The chemical compositions for the various grades of pig iron in use in the United States are shown in table 5.

Iron and steel scrap consists of all ferrous materials either alloyed or unalloyed, of which iron or steel is a principal component, which are the waste of industrial production, or objects that have been discarded because of obsolescence, failure, or other reasons.

Iron and steel scrap is classified as *home scrap, prompt industrial scrap,* or *obsolete scrap. Purchased scrap* consists of the last two classifications.

Home scrap, also known as *revert scrap* or *runaround scrap,* consists of scrap that is produced in steel mills and foundries as a byproduct of their operations, as well as old plant scrap, and it is recirculated to the furnace for remelting. *Prompt industrial scrap* is the waste material resulting from fabrication of iron and steel products. *Obsolete,* or *old scrap* consists of iron or steel products that have been discarded because they are worn out, broken, obsolete, or for other reasons.

Over 100 grades of iron and steel scrap are listed by the Institute of Scrap Iron and Steel. A condensed list of 21 grades is used by the Bureau of Mines for its reports from scrap consumers.

Cast iron is a generic term for the family of high-carbon silicon-iron casting alloys including gray iron, ductile (nodular) iron, malleable iron, and white iron.

Gray (cast) iron is cast iron having a gray fracture and containing a relatively large percentage of the carbon in the form of flake graphite.

Ductile or nodular (cast) iron, is gray iron treated with a nodulizing agent while in the liquid state; when the metal solidifies, the graphite is in nodular rather than flake form. It is also called *spherulitic graphite iron* or *S.G. iron.* Magnesium or a magnesium alloy is the most frequently used nodulizing agent.

White (cast) iron is cast iron possessing a white fracture because all or substantially all of the carbon is in the combined form.

Malleable (cast) iron is a product of heat-treatment of white cast iron to convert the structure into a ferritic (iron) matrix containing nodules of "temper carbon" or graphite.

Various grades of *alloy cast iron* are also made for special purposes, such as heat and corrosion resistance.

Specifications, grades, and compositions of cast iron are given by the American Society for

Table 6.—U.S. pig iron production 1960-77, and number of blast furnaces

Year	Number of blast furnaces (Jan. 1)		Pig iron production (million short tons)
	Total	In blast	
1960	250	218	66.5
1965	231	184	88.2
1970	223	167	91.3
1975	197	135	79.7
1976	195	119	86.8
1977	192	106	p81.3

p Preliminary.

Testing and Materials (ASTM), the Society of Automotive Engineers (SAE), and the American Foundrymen's Society (AFS).

Steel is an iron-base alloy containing up to 2 percent carbon. In practice, it usually contains manganese and residual amounts of silicon, sulfur, and phosphorus, with a carbon content between 0.05 and 1.25 percent.

Raw steel is steel in the first solid state after melting, suitable for further processing or sale, including ingots, steel castings, and strand or pressure cast steel. It is the equivalent of the term *crude steel* as used by the United Nations.

Steels that derive their properties mainly from carbon, with no specified minimum alloy content (other than manganese), are classified as *carbon steels.* Carbon steels are sometimes classified according to carbon content as follows: *High carbon,* over 0.55 percent; *medium carbon,* 0.25 to 0.55 percent; and *low carbon,* or mild steel, under 0.25 percent. They have also sometimes been classified by method of manufacture such as *basic open-hearth, electric arc, Bessemer,* or *basic oxygen.*

Carbon steels are also often classified by degree of deoxidation. *Rimmed steel* contains sufficient oxygen to give a continuous evolution of carbon monoxide while the ingot is solidifying resulting in blowholes in the body of the ingot that are subsequently closed during working and a case or rim of metal virtually free of voids. *Killed steel* is steel deoxidized with aluminum or silicon to reduce the oxygen content to a level such that no reaction between carbon and oxygen occurs during solidification. In *semikilled steel,* smaller quantities of deoxidizers are added so that some oxygen reacts with carbon to form carbon monoxide, which offsets solidification shrinkage. *Capped steel* is semikilled steel cast in a bottle-top mold and covered with a cap fitting into the neck of the mold, which causes the top metal to solidify. Pressure is built up in the sealed-in molten metal and results in a surface condition much like rimmed steel.

Medium and high-carbon steels may be hardened and strengthened by *heat treatment,* consisting of heating to a certain temperature, *quenching* in a cooling medium such as water or oil, and *tempering* by heating to a lower temperature to partially soften the steel and restore ductility. Hardened steel can be softened by *annealing,* generally consisting of heating to the proper temperature and slow cooling.

Low-carbon steels are *case hardened* or *case carburized* by heating in a carbonaceous medium to raise the carbon content of the surface layers of the steel, followed by an appropriate heat treatment to develop the desired properties. The surface may also be hardened by *nitriding* by heating in a nitrogenous medium or by *cyaniding* which is a combination of *carburizing* and *nitriding.*

An *alloy steel* is any steel to which alloying elements (other than carbon and the usual amounts of silicon and manganese) have been added to develop specific properties. *High-strength low-alloy (HSLA)* steels are steels to which small quantities of alloying elements have been added to improve their properties. They are mainly used without heat treatment for construction purposes.

Tool steels are characterized by high hardness and resistance to abrasion, generally attained by high-carbon content, by high-alloy content in many types, and by heat treatment. The *high-speed steels* are tool steels, containing tungsten and/or molybdenum, chromium, and vanadium, which resist softening at elevated temperatures, and hence can be used for machining at high speeds where considerable frictional heat is developed. Many other grades of tool steel have been developed for specific purposes.

Stainless steels usually contain between 12 and 30 percent chromium, which imparts resistance to atmospheric rusting and chemical corrosion of the material. The three main classifications are *ferritic* or *straight chromium, austenitic* or *chromium-nickel,* and *martensitic* or *cutlery grade* stainless steels.

Heat resisting steels contain alloying elements to improve their properties at high temperatures, and they include the stainless steels.

Specifications for the various grades of steel are published by the American Iron and Steel Institute (AISI), SAE, and ASTM. Many of these specifications are also given in the Metals Handbook, v. 1., and in the annual Metal Progress Databooks, both published by the American Society for Metals (ASM).

USES

The uses of iron and steel can be divided into three categories—structural members, coverings and containers, and mechanical ele-

Table 7.—Iron and steel scrap statistical summary, 1972-77

(Thousand short tons)

	1972	1973	1974	1975	1976	1977[p]
Net receipts of purchased scrap	41,670	44,711	51,335	36,753	41,399	42,100
Production of home scrap	51,184	57,801	55,250	46,042	50,026	49,520
Total scrap consumption	93,371	103,589	105,483	82,331	89,910	92,090
Stocks of scrap at yearend	8,169	7,092	8,408	8,766	9,988	9,240

[p] Preliminary.

ments. Structural members, which include framing for buildings, bridges, rail and highway structures and industrial equipment, as well as the supporting members of land vehicles and ships, comprise the largest use of steel. Its use in machine elements probably ranks second, closely followed by its use as a covering or in containers in which its strength is inherent in the skin or shell.

Steel is used as the frame and as reinforcing for the concrete in buildings, bridges, and docks. It is used by building contractors in structural shapes, sheet piling, pipe, rods, and bars. In the automotive industry, iron and steel comprise most of the weight of the mobile equipment produced—in the frame, a structural member; in the body, a covering; and in the engine and drive train, mechanical elements.

Most railroad equipment is built of steel, including cars, locomotives, cranes, track, trolley supports, and switches. Modern ships are built almost entirely of steel, as are many small boats and pleasure craft. Alloy steels are used in the structural members of aircraft and some parts of the engines not subject to high temperatures. Steel is vital to the oil and gas industry for drill rods and pipe in the wells and for pipe in transmission lines. Practically all mining, agricultural, and industrial mechanical equipment is made of steel. The frames for commercial and consumer electrical equipment and appliances normally are made of steel as are most of the machine elements. Steel's use in containers ranges from the common tin can through barrels to large storage tanks. Steel is used in many military applications, such as tanks, guns, and other munitions.

TECHNOLOGY

Blast Furnace

The modern blast furnace resembles its forerunners in its essentials. It consists of a refractory-lined steel shaft in which the charge is continuously added to the top through a gas seal and preheated air is blown in through the *tuyeres* at the *bosh* near the bottom to be emitted as combustible gas (*top gas*). Iron and slag are intermittently tapped from the *hearth* at the bottom. The furnace has high thermal efficiency because of the countercurrent flow of solids descending and hot gases rising from the combustion zone and transferring their heat to the charge. The charge consists principally of iron ore, sinter or pellets, coke, and limestone or dolomite; iron or steel scrap may be added in small amounts. The chemical reactions are complex; the main reactions are combustion of coke to produce carbon monoxide, reduction of the iron ore to iron by the carbon monoxide, and fluxing of the silica and alumina in the ore and the coke ash with limestone to form a slag which absorbs some sulfur from the charge.

Preheated air up to 2000° F. for the furnace is supplied by refractory-lined, checker-brick stoves heated by burning cleaned top gas. The molten pig iron, which has dissolved some carbon and silicon, is generally tapped into a transfer ladle, which delivers the hot metal to the steelmaking plant. The metal may also be cast into pigs for subsequent sale or use. Slag is tapped into ladle cars for hauling to the slag dump, allowed to solidify in a slag pit, or granulated with water. Blast furnace slag is used for concrete aggregate, railroad ballast, soil conditioner, or landfill.

In recent years the size, productivity, and efficiency of blast furnaces have greatly increased. The largest modern blast furnaces have working volumes 2.5 times that of furnaces constructed in the 1940's, and productivity per unit of working volume has increased over 3.5 times. Productivity of the blast furnace has been increased by improved charge quality and preparation, including use of sized ore, pellets and sinter, better fuel and refractories, higher blast temperatures and volumes, humidity control, fuel and oxygen injection, and high top pressure.

Direct-Reduced Iron

Direct-reduced iron, also known as prereduced iron or sponge iron, is produced by several processes by which iron ore or pellets are reduced to solid iron by solid, liquid, or gaseous reductants. For steelmaking, direct-re-

Table 8.—Proportions of iron and steel scrap and pig iron used in furnaces in the United States

(Percent)

Type of furnace	1960		1965		1970		1975		1976		1977[p]	
	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron
Basic oxygen	28.1	71.9	29.6	70.4	30.1	69.1	28.3	71.7	28.4	71.6	28.2	71.8
Open hearth	41.7	58.3	41.6	58.4	41.4	58.6	44.7	55.3	44.5	55.5	48.8	51.2
Electric	[1] 96.4	[1] 3.6	[2] 97.7	[2] 2.3	98.1	1.9	96.7	3.3	98.1	1.9	97.6	2.4
Cupola	72.4	27.6	79.7	20.3	86.2	13.8	89.6	10.4	91.8	8.2	92.5	7.5
Bessemer	10.1	89.9	10.9	89.1	----	----	----	----	----	----	----	----

[p] Prelimonary.
[1] Includes crucible furnace.
[2] Includes crucible furnace and vacuum melting.

duced iron should not contain more than a small percentage of the slag-forming materials silica and alumina (the less the better, and preferably no more than 4 percent). Direct-reduced iron may be in the form of lump, briquettes, pellets, or unconsolidated fines depending on the original raw material and the process used to produce it. Normally it is less than 1 inch in maximum dimension except for briquetted fines which may reach 3 inches.

Direct-reduced iron can be used to replace all or part of the pig iron or scrap in cold-melt steelmaking and foundry operations. It is most efficiently used by continuous charging through the electric arc furnace roof during melting, rather than charging in large batches as is done with scrap. Direct-reduced iron is especially valuable for feed to electric arc furnaces making high-grade steel because it is much lower in the tramp elements normally found in most scrap.

Scrap

Iron and steel scrap is an important raw material both in steelmaking and in foundry production. Table 7 presents a summary of scrap statistics for 1972–77.

In the last decade, the consumption of scrap for all purposes has remained at about the same level as consumption of pig iron. For steelmaking, the proportion has been 43 to 46 percent scrap; for steel foundries it was 95 to 98 percent; and for iron foundries and miscellaneous users, it has ranged from 83 to 89 percent. The proportions of iron and steel scrap and pig iron used in various types of furnaces in the United States are shown in table 8.

The principal types of scrap are defined in the section on definitions, grades, and specifications. Home scrap constituted 52 to 61 percent of the total scrap consumed in the past decade. Purchased scrap consisted of roughly equal amounts of prompt industrial and obsolete scrap. The sources of obsolete scrap include railroads, junked automobiles, farm scrap, public utilities, shipbreaking, demolition of structures, and many miscellaneous sources. Only a small proportion is derived from municipal waste.

The scrap industry consists of collectors and small dealers, large dealer-processors, and brokers. Collectors and small dealers generally handle all types of waste, and the large dealers and processors specialize in iron and steel scrap, nonferrous metals, waste paper, etc. Processors of scrap employ a large variety of equipment. Shears of various types are used for cutting bulk scrap and flattened automobile bodies to manageable size. Balers are hydraulic presses capable of compressing an automobile body or other light scrap into a dense cube. One of the latest developments is the shredder or fragmentizer, which is capable of reducing an automobile to fist-size pieces of scrap in less than 1 minute. The iron and steel fraction is magnetically separated from the other materials to produce high-quality scrap. Shredders, depending on their size, can process from 25,000 to 250,000 cars a year. In 1977, 3.2 million tons of shredded scrap was consumed domestically and 1.6 million tons was exported.

Another recent development is the mobile car crusher, which flattens cars prior to shipment to the scrap yard, and makes possible the more economic transportation of scrapped automobiles over greater distances.

Other processing equipment includes the cutting torch, the drop ball for breaking cast iron scrap, the rail breaker, and the briquetter and turnings crusher for compacting turnings and borings.

Materials handling equipment includes belt conveyors and overhead and crawler cranes equipped with electromagnets or grapples.

Steelmaking

All contemporary steelmaking processes convert pig iron, scrap, or direct-reduced iron, or mixtures of these, into steel by a refining process that lowers the carbon and silicon contents and removes impurities, mainly phos-

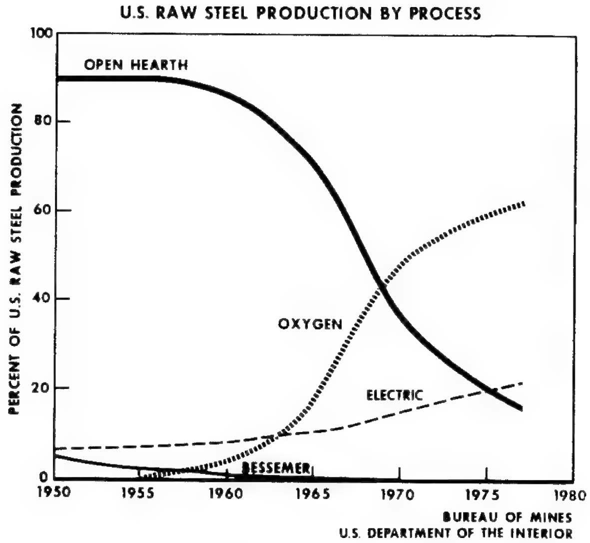

Figure 1.—U.S. raw steel by production by process, 1950–77. Source: American Iron and Steel Institute.

Data for Figure 1.—U.S. raw steel production by process

(Percent)

Year	Open-hearth	Bessemer	Oxygen	Electric
1950	89.1	4.7	----	6.2
1955	90.0	2.8	0.3	6.9
1960	87.0	1.2	3.4	8.4
1965	71.7	0.4	17.4	10.5
1970	36.5	----	48.2	15.3
1973	26.4	----	55.2	18.4
1974	24.3	----	56.0	19.7
1975	19.0	----	61.6	19.4
1976	18.3	----	62.4	19.2
1977[p]	16.1	----	62.0	21.9

[p] Preliminary.
Source: American Iron and Steel Institute.

phorus and sulfur. The excess oxygen remaining in the molten steel is then neutralized by adding deoxidizing elements such as manganese, silicon, or aluminum.

The first commercially developed process for producing steel in tonnage quantities was the Bessemer process, in which air was blown through a bath of molten pig iron in a pear-shaped converter. Because the Bessemer process was unable to remove phosphorus, produced steel with a high nitrogen content, and was unable to utilize much scrap, it was gradually replaced by the basic open-hearth process in the United States. The Thomas process, which utilizes a basic-lined converter, is still used to some extent in Europe.

The basic open-hearth process was the dominant steelmaking method in the United States between 1908 and 1969. In this process, a relatively shallow bath of metal is heated by a flame which passes over the bath from burners at one end of the furnace, while the hot gases resulting from combustion are used to heat checker-brick regenerators at the other end of

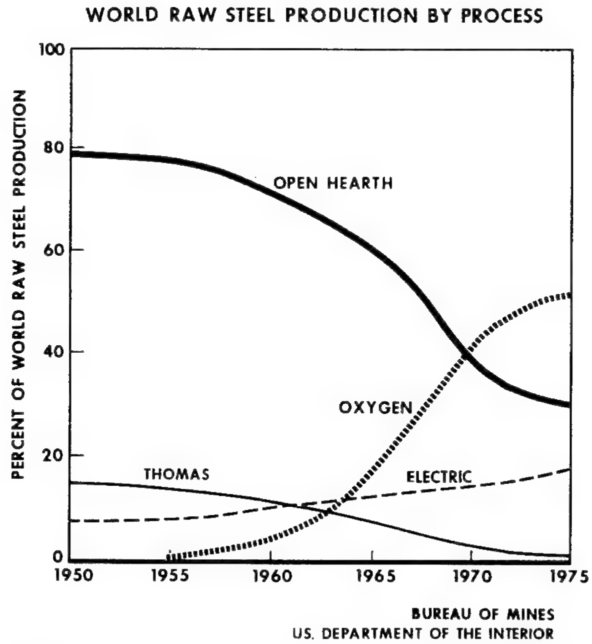

Figure 2.—World raw steel production by process, 1950–75. Source: Iron and Steel. Federal Statistical Bureau, Dusseldorf Field Office. West Germany, 4th quarter 1977 edition.

Data for Figure 2.—World raw steel production by process

(Percent)

Year	Open-hearth	Thomas	Oxygen	Electric	Other[1]
1950	78.7	14.1	0.0	7.2	----
1955	77.9	13.8	0.3	8.0	----
1960	71.8	11.8	4.1	11.0	1.3
1965	61.0	7.8	17.7	12.7	0.8
1970	39.4	4.0	41.1	14.7	0.3
1972	34.2	2.8	46.7	16.0	0.3
1973	32.1	2.2	49.2	16.3	0.2
1974	30.4	1.8	50.7	16.9	0.2
1975	30.5	1.1	51.1	17.1	0.2

[1] Included with Thomas process prior to 1960.
Source: Iron and Steel. Federal Statistical Bureau, Dusseldorf Field Office, West Germany, 4th quarter 1977 ed.

the furnace. Periodically, the direction of the flame is reversed, the hot checker-bricks preheating the air for combustion, and the exhaust gases reheating the checkers at the other end of the furnace; gas, oil, or tar can be used as fuel.

The bath is covered by a chemically basic slag which serves to remove phosphorus and, to some extent, sulfur. Carbon is removed from the bath by introduction of ore or by oxygen injection. By this process, a batch or *heat* of up to 420 tons of steel can be made in a period of 6 to 8 hours. The process is flexible in the proportion of pig iron and scrap that can be charged; in current practice, the proportions are about 45 percent scrap and 55 percent pig iron. The pig iron is generally charged in the molten form, as hot metal directly from the blast furnace.

The electric arc furnace has been used since its inception at the beginning of the century for the production of stainless and alloy steels, including tool steels. Since about the end of World War II, it has been increasingly used for the tonnage production of plain carbon steels. In almost all cases, the electric arc furnaces operate with a cold charge in which the ferrous content is close to 100 percent scrap. Direct-reduced iron is a potential substitute for scrap, and it is used as the major iron input in some electric arc furnace plants.

Close control of quality can be obtained in the basic electric arc furnace, and sulfur can be removed using special slags. One advantage of the electric arc furnace process is its relatively low capital cost per ton of steel produced. Plants can be located to take advantage of local supplies of scrap, and of local markets for steel. Small electric arc furnace plants have come to be known as minimills. These are located where large integrated steel mills would be uneconomical in many parts of the United States, in Europe, especially in Italy and Spain, in Japan, and in the developing countries.

In making stainless steel in the electric arc furnace, oxygen lancing has long been used to reduce the carbon to the required low level. Processes have recently been developed in which the metal is first melted in the electric arc furnace and refined in a second vessel, using combinations of oxygen with argon, vacuum, or steam for decarburization. Over 90 percent of stainless steel is now produced by the argon-oxygen-decarburization (AOD) process. This has indirectly enabled the use of a lower grade of chromite ore from diverse sources.

Other recent developments in electric arc furnace melting include the use of ultra-high power; that is, operation at about twice the power rating formerly used for a given size furnace, which reduces the melting time by about one-half. These high-power levels have stimulated development of high conductivity graphite electrodes, coatings of electrodes to reduce oxidation losses, water-cooled power cables, water-cooled panels in the furnace shell, and improved refractories.

The electric induction furnace differs from the electric arc furnace in that the metal is heated by induced electric current within the charge rather than by an arc. Induction furnaces are generally smaller than electric arc furnaces, and often they are used in iron and steel foundries and for special purposes such as melting under vacuum or in an inert atmosphere, and melting of relatively high-purity charge materials.

The latest entry into the steelmaking process is the basic oxygen process (BOP), which was developed in Austria as the Linz-Donawitz (L-D) process. Beginning in the early 1950's in the United States, it is now the dominant steelmaking process in this country. In this process, a jet of pure oxygen is injected into the molten metal by a lance of regulated height in a basic refractory-lined converter. Excess carbon, silicon, and other reactive elements are oxidized during the controlled blows, and fluxes are added to form a slag. A heat of up to 350 tons of steel can be produced in approximately 45 minutes. Under present practice the charge consists of about 28 percent scrap with the balance molten pig iron.

A variation on the basic oxygen process is the bottom-blown or OBM process, which was invented in Canada and developed in West Germany. It was first used in the conversion of many of the remaining Thomas converters in Europe. The process employs a sheath of some hydrocarbon, such as propane or natural gas around the oxygen stream that is injected into the bottom of the converter. The gas cools and protects the tuyeres or injection ports. Lime may be injected into the bath with the oxygen for control of phosphorus or limestone added to the converter prior to the charge. The converted Thomas converters range from 5 to 80 tons; the first large bottom-blown oxygen converters, termed Q-BOP, and having a capacity of 200 tons, were built by the United States Steel Corp. in the United States. The bottom-blown process is said to have lower construction costs and higher production rates and yields compared with the top-blown process.

The changes in the pattern of steelmaking processes in the United States since 1950 are shown in figure 1.

On a worldwide basis, the proportion of steel production by various processes is shown in figure 2.

In early 1977, world oxygen steelmaking capacity was 514 million short tons, with Japan, the United States, and West Germany having 26 percent, 17 percent, and 10 percent of the total.

Vacuum degassing is the treatment of molten steel in a low-pressure environment to remove dissolved gases, chiefly hydrogen and oxygen, to improve the properties of the steel, or to produce steel of very low carbon content. Vacuum degassing on a large scale has been practiced since around 1950. Three main methods are used: (1) *Stream degassing* in which a falling stream of molten metal is exposed to a low-pressure atmosphere, (2) *ladle degassing*

which is accomplished by placing a ladle of molten steel in a vacuum chamber and stirring the metal, (3) and *recirculation degassing* in which the molten steel flows through a special vacuum chamber to progressively expose portions of the steel bath to a partial vacuum.

Consumable electrode remelting processes are used to produce high-quality steel for special purposes. These processes include *vacuum arc remelting,* and *electroslag remelting.* Elimination of ingot segregation and better ingot surface, density, and yield are among the advantages. The processes consist of remelting electrodes of the steel to be refined by an arc under a vacuum or controlled atmosphere or a slag cover.

Additive Elements in Steel

Several elements may be added to molten steel to remove dissolved oxygen (*deoxidation*), to control the embrittling effects of sulfur, or to change the properties of the finished steel. The main functions of the more common additive elements are shown in table 9. *Hardenability* is a measure of the depth of hardening of a steel section when *quenched* in water, oil, or other medium, and it is useful in steels that are to be heat treated. High-temperature hardness and strength are useful in cutting tools and in high-temperature applications.

Table 9.—Additive elements in steel

Element	Function in steel
Aluminum	Deoxidation, grain-size control.
Chromium	Hardenability, high-temperature strength, corrosion resistance.
Cobalt	High-temperature hardness.
Columbium	As-rolled strength.
Copper	Corrosion resistance, precipitation hardening.
Lead	Machinability.
Manganese	Deoxidation, sulfur control, hardenability.
Molybdenum	Hardenability, high-temperature hardness, temper brittleness control.
Nickel	Hardenability, low-temperature toughness.
Rare earths	Inclusion control, ductility, toughness.
Silicon	Deoxidation, electrical properties.
Sulfur	Machinability.
Tungsten	High-temperature hardness, hardenability.
Vanadium	Grain-size control, hardenability, high-temperature hardness.

Casting

After the steel has been refined in the open hearth, basic oxygen, or electric arc furnace, it is transferred to a refractory-lined ladle and poured through a nozzle in the bottom into ingot molds or through a refractory-lined tundish into a continuous-casting machine. Ingot molds are tall cast-iron containers weighing from 1 to 1.5 times as much as the ingots cast in them. The molds are usually tapered to facilitate removal of the ingots, which may range in size from a few hundred pounds for specialty steels to 300 or more tons for large forging ingots; however, most ingots are in the 10- to 40-ton range. The exact shape of the ingot is determined by the products to be made from it.

Casting of steel into continuous strands, which are then cut into blooms, billets, or slabs (terms defined in the section on rolling), has the advantage of producing a higher yield than ingot casting and eliminating the primary hot-rolling process. Continuous casting of steel on a commercial scale originated in Europe in the early 1950's, and was introduced in the United States, generally as large-scale units, during the 1960's. Continuous-casting machines consist basically of a relatively short, water-cooled copper mold; a cooling chamber containing water sprays below the mold; pinch rolls, and rollers for supporting the casting beyond the cooling chamber. The mold generally oscillates vertically to prevent sticking of the casting. When the molten steel comes into contact with the mold, a thin skin of solid metal forms; the center of the casting remains molten until some distance below the bottom of the mold where it is finally solidified by the water sprays in the cooling chamber. The steel from the ladle is poured into a container known as a *tundish,* from which it flows into the mold through a nozzle in the bottom. The tundish may have two or more nozzles for simultaneous pouring into a multiple-strand machine. There are three basic designs in contemporary use: Vertical casting, in which the vertical steel strand is torch-cut into slabs which are then lowered into the horizontal position; the vertical-plus-bending machine, in which the casting is bent into the horizontal position; and the semihorizontal, or curved-mold design, which uses a specially designed mold and a curved cooling chamber, which permits the height of the machine to be about one-third that of the other types. Cross sections of from 2 inches square to slabs 12 by 84 inches have been successfully cast, and stainless, alloy, tool, and carbon steels have all been successfully cast.

Another process, used to limited extent, is bottom-pressure pouring of blooms, billets, or slabs in which the molten steel is forced by air pressure into graphite molds, where it solidifies.

Rolling and Forging

After ingots have been stripped from their molds, they are reheated in *soaking pits* to bring them to a uniform temperature of 2,150° to

2,450° F prior to rolling in a *primary mill*. Soaking pits are large furnaces, usually below ground level, heated by oil, gas, or electricity. A primary mill reduces ingots to *blooms, billets,* or *slabs* by a process of gradual compression between two rotating rolls driven by a powerful electric motor. Several passes through one or more sets of rolls (*stands*) are required to reduce an ingot to final size. Blooms and billets are mostly square in cross section, differing only in size; blooms generally range from 6 to 12 inches square, and billets range from 2 to 5 inches square. Slabs are oblong in cross section, usually ranging from 2 to 9 inches thick and 24 to 60 inches wide, although thicker and wider slabs may be produced. These products are known as semifinished steel. After primary rolling, ends of the still-hot products are cropped to remove defective material. Blooms, billets, or slabs may be continuously rolled further in one operation to intermediate or finished products; however, they are usually cooled and stored. Before the next processing step, most material is *surface conditioned* to remove defects by *grinding* or by *scarfing* with an oxygen torch.

Reheated semifinished steel is processed either into *flat-rolled products* or into rails, structural or other shapes, bars, wire rods, pipe, or tubing. Flat-rolled products are produced on smooth-faced rolls in contrast to grooved rolls used to make the other products. Flat-rolled products include *plates, sheet, strip, tinplate* and *blackplate,* and other products such as *skelp,* which is used to make welded pipe. Blackplate, a misnomer remaining from blacksmith days, is merely a wide and thin form of cold-rolled steel sheet used mainly to make tinplate. About half of all steel rolled in the United States is flat-rolled. Sheet, strip, blackplate, and tinplate comprise about three-fourths of all flat-rolled material. Hot-rolled bands are intermediates obtained by hot rolling an ingot, slab, or billet until its thickness has been reduced to $^1/_8$ to $^1/_4$ inch and are further processed by cold rolling.

Sheet and strip differ only in width and thickness and are both produced on *continuous hot strip mills*. Carbon steel strip ranges from $3^1/_2$ to 12 inches wide and may be thinner than sheet, whereas sheet is over 12 inches wide.

A continuous hot strip mill consists of one or more sets, or *stands* of *roughing rolls* and a final series of *finishing rolls*. Finishing rolls, and some roughing rolls are *four-high,* that is, they consist of four rolls arranged vertically, with one pair of smaller *work rolls* that deform the steel and one pair of larger *backup rolls* that prevent excess deflection of the work rolls: Hot rolling usually begins at 2,200° F and finishes well above 1,300° F. The product of the hot strip mill may either be used without further rolling or further processed by *cold rolling*.

If sheet or strip is to be processed further, it is necessary to remove the oxide coating or *mill scale* from the surface. In most cases this is done by *pickling,* that is, chemically removing the scale with a solution of hydrochloric or sulfuric acid. In some cases, *shot or grit blasting* is used to remove the scale. After *descaling,* the steel is coated lightly with oil to prevent rusting. Most hot-rolled material is given a light cold pass through *temper-rolls* to improve flatness, surface quality, and mechanical properties. The product is usually coiled; if cut into sheets, it is usually flattened or *leveled*. Coiled material may be *slit* into narrower widths on a *slitting line* and recoiled.

Plate is a flat-rolled product heavier than sheet. Plates up to 48 inches wide have a minimum thickness of 0.23 inch; with plates over 48 inches wide, the minimum thickness is 0.18 inch. Plate is used for fabricated structures such as bridges, storage tanks, pressure vessels, railway cars, and ships.

Railroad rails, structural and other shapes, *bars,* and *rods* are rolled on grooved rolls in several passes, the final pass being through grooves having the dimensions of the finished product. Structural shapes include *I-beams, angles, channels,* and *wide-flange beams*. Other shapes include miscellaneous sections for special purposes. Bars may be round, square, or hexagonal in cross section.

Wire rod, which is also hot-rolled on grooved rolls, is the starting material for wire drawing. *Seamless tubing* is rolled on special mills equipped with *piercing mandrels* for forming the inside bore.

Forging is a form of hot-working that may be done by *hammering* or *pressing,* usually with a die for controlling shape. Hammers are operated by steam, compressed air, or electromechanical devices; presses are either hydraulic or mechanical.

Extrusion is a related hot-working process. A machine-driven ram shapes metal confined within a tubular container by pushing the metal out through a die opening at the opposite end of the container.

Cold Rolling

Making flat products is an important part of steel production, accounting for over 60 percent of total industry shipments in 1977. About two-thirds of flat steel is produced by cold rolling, in which the only heating the steel

receives is a small amount from frictional effects during deformation. Cold-rolled steel is stronger and has better surface and dimensional characteristics than hot-rolled steel. Most cold rolling is done continuously, semifinished steel (hot-rolled bands) being fed through rolls from a coil.

Steel is most frequently cold-rolled in four-high mills in which each work roll is backed by a larger roll with all rolls being vertically alined. In a continuous-tandem mill, three to six such four-high roll stands are arranged in a line. Material from a coil is reduced progressively as it advances through each stand. Some steel is rolled using single-stand, four-high reversing mills; the steel is rolled first in one direction and then in the reverse direction until the final gage is reached. Another type of mill used for special applications is the Sendzimir mill, which had a clustered arrangement of backup rolls for transmitting force to the work rolls. In addition to roll stands, a typical cold mill will also have other equipment or lines for intermediate annealing and cleaning of steel. Some form of heat-treatment is applied to most cold-rolled sheet or strip to restore the ductility lost in cold reduction, except when it is desired to take advantage of the high strength developed in cold rolling.

Coatings for Steel

Common steel will rust and corrode. To prevent this and to expand its use, several protective coatings for steel have been developed. These coatings include, singly or in combination, other metals such as aluminum, chromium, nickel, lead, tin, and zinc, vitreous enamel, organic paints, varnishes, enamels, lacquers, and plastic. Most important of the metallic coatings for flat-rolled steel are zinc, tin, and chromium. In 1977, over 6 percent of all steel shipped was galvanized, nearly 5 percent was tinplate, and about 1 percent was tin-free steel electroplated with chromium.

Continuous hot-dip galvanizing, a method developed in the mid-1930's, is used in over 90 percent of galvanized steel production. In this method a prepared coil of either hot- or cold-rolled steel is passed through a molten zinc bath. Relatively thick coatings of about one-thousandth of an inch are produced. Galvanized steel is used in the automotive and construction industries, and in a wide range of other applications. An operation similar to galvanizing is used to manufacture *long terne* sheet, which is steel coated with a lead-tin alloy. Long terne sheet is a small tonnage item especially suited for gasoline tanks.

Tin cans are made from tinplate, which is produced by a continuous process of electrolytic deposition of a tin layer onto cold-rolled sheet steel. Subsequent heating of the as-plated steel fuses the coating and gives it a metallic luster. Thickness of the tin layer amounts to only tens of a millionth of an inch. Electrolytic tinplate manufacture began superseding hot dipping in the United States in 1937.

Production of tinplate has declined somewhat in recent years, partly because of competition from aluminum cans and partly because of the development of tin-free steel which is made from the same steel as tinplate but coated instead with chromium. The coating is thinner than tin coatings, it is put on electrolytically, and it is lacquered to make it suitable for certain food and beverage containers.

Foundry

Iron and steel foundries produce *castings*, which are ready for use after a minimum of processing, by pouring molten metal into molds. Among the advantages of the casting process are: (1) It can produce complex parts in one piece; (2) it is the most direct method of converting raw materials to finished products; (3) products in a wide range of sizes and shapes can be cast; and (4) castings can be designed with the metal distributed for maximum efficiency for strength, wear resistance, or other properties.

Molds for iron and steel castings are made from special sand mixtures or other materials. First, a pattern of the object to be cast is made, usually of wood; then the sand mixture is compacted around the pattern in a box-like container known as a *flask,* divided into a bottom part (the *drag*), and a top part (the *cope*). Opening the divided mold permits the pattern to be removed, so that reassembly leaves a cavity of the required shape for the casting. To produce hollow or other special shapes, *cores,* made of hardened sand mixtures, are placed in the molds. Molten metal is poured into the mold through passages known as sprues and gates, and special cavities known as risers are sometimes included to allow for shrinkage of the metal as it solidifies.

Iron and steel foundries account for about 80 percent of all foundry production, the remainder being nonferrous. Shipments of iron and steel castings amounted to about 17.7 million tons in 1977.

Iron foundries produce gray, ductile,and malleable iron castings. About 80 percent of these are gray iron castings. Metallic raw mate-

rials for iron castings are scrap iron and steel and pig iron. Since 1956, the proportion of scrap in the charge has increased from 65 to 87 percent. This trend is due to economic factors including the relative price of scrap and pig iron, and the gradual decline in the number of merchant pig iron producers. The predominant means of melting the charge in iron foundries is a refractory-lined shaft furnace, called a *cupola*. However, in recent years, electric arc furnace melting and induction melting have become increasingly important. The induction furnace is also used in combination with the cupola or electric arc furnace for increasing the metal temperature and as a holding furnace. The air furnace, a type of reverberatory furnace, accounts for a small proportion of the total production. Cupolas having water-cooled walls, hot blast, and other design improvements have been introduced in recent years. In Europe, and to some extent in the United States, a rotating variant of the air furnace has been used.

The iron foundry industry historically has consisted of many small operations, with only a few large plants. However, the trend is toward larger foundries, with increasing use of automation in the operations of sand and mold preparation, pouring of castings, and subsequent handling.

Steel foundries differ from iron foundries mainly in the higher temperatures and lower carbon contents required to produce steel rather than cast iron. Melting is done mostly in electric arc furnaces. Induction furnaces are used to a limited extent for melting special grades of steel. Steel castings are also made by some producers of steel ingots.

Current Research and Applications

Research and engineering on making, shaping, and treating of steel is conducted or supported by the steel industry, by supplier companies, and by governmental agencies. Applied research and development accounts for about 98 percent of the total; basic research accounts for the balance. National Science Foundation figures for the primary ferrous metals and products industry show average company expenditures of about $145 million annually, ranging from $136 to $159 million in 1970–74, for applied research and development and for basic research(*23*). Company-financed contract research and development has amounted to about $6 million per year. The American Iron and Steel Institute, the industry trade association, supports university research. Federally funded research in steel has totaled $1 to $4 million annually.

Research on basic oxygen steelmaking has centered on the physics and chemistry of the process to achieve precise control of the operation and of the end product. Considerable effort has been spent on development of sampling and sensing devices suited to rapid determination of temperature and metal chemistry. Experimentation with blowing techniques has led to annular coinjection of hydrocarbons with oxygen through the converter bottom (the OBM or Q-BOP process), which may prove more advantageous than conventional top-lancing.

Development of a fully continuous process for steelmaking is often cited as a steelmaker's dream. Partial achievement of this goal has been reached in electric arc furnace steelmaking. Bureau of Mines and industry researchers have studied ways of continuously feeding and melting metallic charges with consequent savings in heat times and energy requirements. Continuous rather than batch charging techniques have been tested for both scrap and prereduced ore charges. Practices developed have been commercialized as exemplified in the melt shops of modern minimills. Other studies have sought to improve furnace refractory life through development of methods for monitoring furnace sidewall temperatures and by use of water-cooled sidewall panels.

Several specialized melting and processing techniques and furnaces have been developed to produce superior grades of alloy steels. One specialized process finding a niche is atomization of a liquid alloy steel followed by powder-metallurgical consolidation of the resultant fine particles. This process was developed to increase the microscopic uniformity of high-speed and tool steels difficult to produce to consistent quality standards by conventional methods. Application of this procedure has advanced from laboratory to commercial tonnage application.

In addition to performing research on iron-making and steelmaking processes, the Bureau of Mines has been active in extending iron resources by finding ways to utilize low-grade materials. This work has sought to make acceptable products from steel scrap and wastes containing objectionable amounts of elements such as copper, tin, zinc, and lead. These problem elements are encountered in lower grades of scrap, steel plant flue dusts, and in the ferrous fraction of municipal refuse. The program on making use of these iron sources included the development of smokeless incineration of junk automobiles and railroad box

Table 10.—Iron and steel supply-demand relationships, 1968-77

(Million short tons, iron or steel)

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977[p]
Raw steel production:										
United States	131.5	141.3	131.5	120.4	133.2	150.8	145.7	116.6	128.0	124.7
Rest of world	451.0	490.7	522.7	519.5	561.3	616.4	637.1	596.0	620.5	617.2
Total	582.5	632.0	654.2	639.9	694.5	767.2	782.8	712.6	748.5	741.9
Finished iron and steel—components of U.S. supply:										
Steel mill shipments	91.9	93.9	90.8	87.0	91.8	111.4	109.5	80.0	89.4	91.1
Imports—steel mill products	18.0	14.0	13.4	18.3	17.7	15.2	16.0	12.0	14.3	19.3
Foundry shipments—iron	16.1	17.1	14.8	14.4	16.3	18.1	16.6	13.2	15.0	[e]16.0
Foundry shipments—steel	1.6	1.9	1.7	1.6	1.6	1.9	2.1	1.9	1.8	[e]1.7
Exports—steel mill products[1]	(2.2)	(5.2)	(7.1)	(2.8)	(2.9)	(4.1)	(5.8)	(3.0)	(2.7)	(2.0)
Total	125.4	121.7	113.6	118.5	124.5	142.5	138.4	104.1	117.8	126.1
Stock adjustment to iron supply[1]	(8.4)	4.8	3.3	(10.4)	.4	----	----	----	----	----
Demand	117.0	126.5	116.9	108.1	124.9	142.5	138.4	104.1	117.8	126.1
U.S. demand pattern:										
Transportation	31.0	30.8	26.3	29.0	30.2	42.2	37.7	29.5	38.0	40.2
Construction	29.9	30.2	29.0	27.9	29.7	40.4	37.9	28.2	30.3	32.0
Machinery	21.3	22.0	20.4	19.4	21.6	28.5	29.3	21.0	23.7	25.3
Cans and containers	8.7	7.9	8.5	7.9	7.3	8.9	9.4	6.7	8.0	8.1
Oil and gas industries	5.2	5.2	4.9	5.1	5.6	7.8	8.3	7.2	6.8	8.4
Appliances and equipment	6.0	6.2	6.0	5.7	6.4	8.5	8.1	5.3	6.5	7.2
Other	14.9	24.2	21.8	13.1	24.1	6.2	7.7	6.2	4.5	4.9

[e] Estimated.
[p] Preliminary.
[1] Figures in parentheses are negative.

cars, which is a processing method particularly applicable to localities where shredding is not practiced.

The Bureau of Mines has also conducted research on reclaiming chromium, nickel, and molybdenum from stainless steel furnace flue dust in a form suitable for recycling.

Pilot plant studies by the Bureau of Mines demonstrated the feasibility of utilizing the heat from the offgases from a basic oxygen furnace (BOF) to preheat charge scrap. Hot gases generated during oxygen blowing of a small experimental BOF were passed through a bed of shredded automobile scrap before charging it to the next furnace heat. These studies showed that the normal 28 percent of scrap in the charge could be increased to as high as 40 percent by preheating without affecting the melt time.

The Bureau of Mines is also seeking ways to improve the technology of cast iron. Projects have included determination of the deleterious effects of contaminants such as tin and copper on ductile iron castings and development of methods to alleviate these effects, development of hybrid cast irons having damping properties intermediate between those of gray and ductile cast iron, and determination of the effects of aluminum on castability, structure, and properties of ductile iron.

SUPPLY-DEMAND RELATIONSHIPS

U.S. and World

Raw steel supply in the United States is dependent upon the capacity of the steelmaking plants to make steel from iron and steel scrap and pig iron, with additions of iron ore and the alloying elements nickel, manganese, tungsten, chromium, silicon, molybdenum, columbium, vanadium, cobalt, and aluminum. The rest-of-the-world supply of raw steel is dependent upon the capacity of steelmaking plants principally in Japan, Western European countries, and the U.S.S.R. World production in 1976 is shown on the supply-demand relationship chart (fig. 3). Materials used in foreign countries to make steel are essentially the same as those used in the United States.

Raw steel is changed into steel mill products by forming and shaping processes in which approximately 30 percent of the steel becomes scrap and is recirculated. Steel mills produce several hundred types of steel, which are designed for various uses. They are broadly classified as carbon, stainless, and alloy steels.

Raw materials, except iron ore, used by iron and steel foundries are essentially the same as those used by steel mills, but most foundries are dependent upon outside sources of scrap, merchant pig iron, coke, and ferroalloys. As in steel mill operations, some part of foundry gross output is scrapped and returned to the circuit. However, unlike raw steel production, gross foundry output is not reported. Steel castings shipped from foundries may fall into the same categories as those of steel mill products, carbon, stainless, and alloy steels. Iron castings are classified in three principal types: gray, ductile, and malleable iron, each of which is produced in several grades.

In the 10-year period 1968–77, steel mill shipments have averaged about 94 million tons per year, ranging from a low of 80 million tons

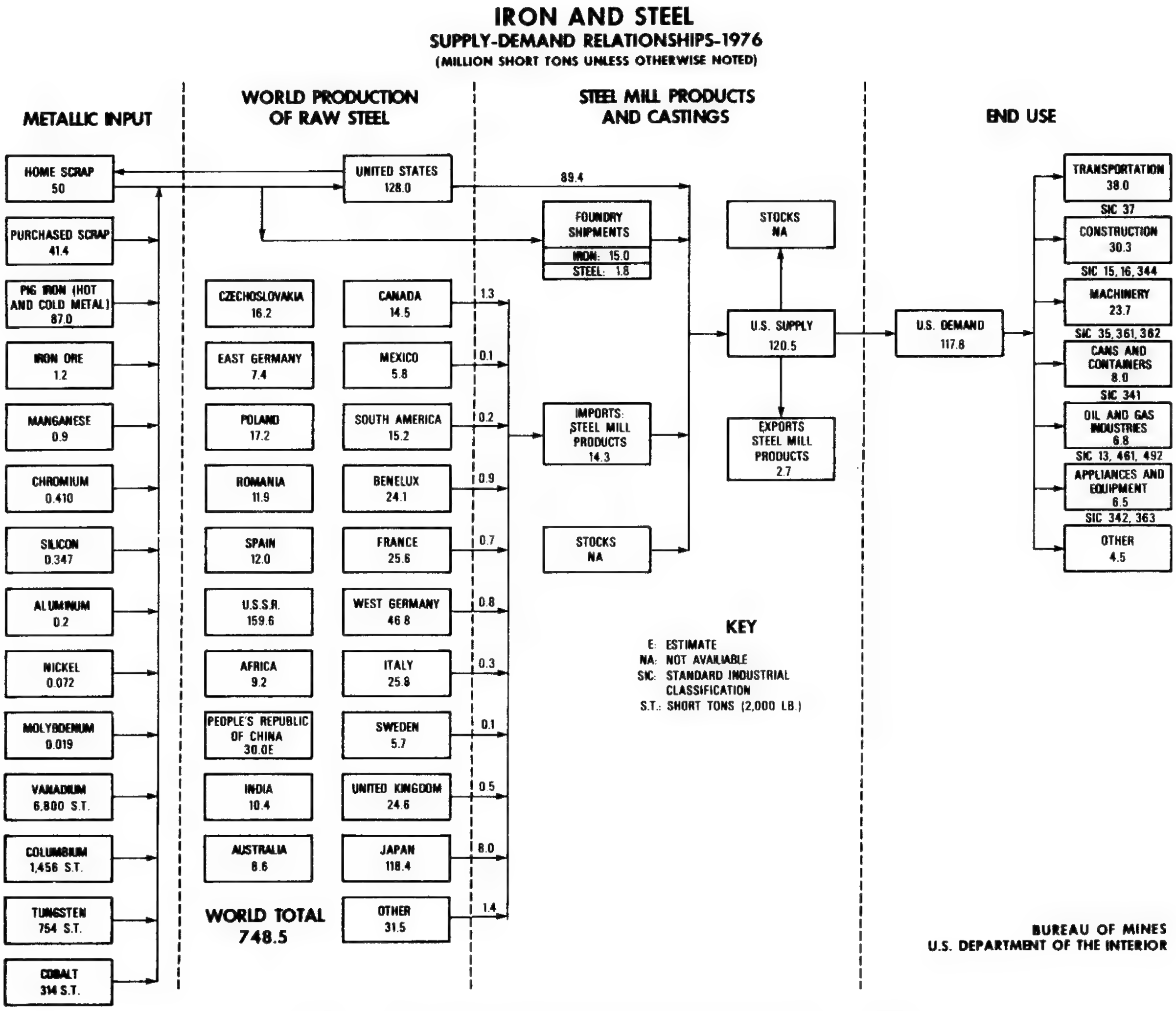

Figure 3.—Supply-demand relationships for iron and steel, 1976.

in 1970 to a high of 111 million tons in 1973. During that time, imports averaged about 16 million tons per year and comprised 15 percent of apparent steel supply, ranging from a low of 12 percent of the total in 1973 to 18 percent of the total in 1971 and 1977.

Foundry shipments of iron castings in the last 10 years have averaged 16 million tons and have not varied significantly from this average, ranging from a low of 13.2 million tons in 1975 to a high of 18.1 million tons in 1973. Foundry shipments of steel castings have followed essentially the same pattern, averaging 1.8 million tons over the 10-year period, and reaching a high of 2.1 million tons in 1974 and a low of 1.6 million tons in 1968, 1971, and 1972.

Steel mill products are held in inventory at steel mills, steel service centers, and by consumers. In normal times the quantity of steel mill products in inventory is relatively constant, but in times of threatened shortage such as an impending labor strike or in times of a large imbalance between supply and demand, producers, service centers, and consumers all tend to build up their inventories. The large negative stock adjustments in 1968 and 1971 (see table 10) were the direct result of unsettled labor relations. The supply-demand data in table 10 were developed using apparent demand between 1968 and 1972 calculating iron supply from the iron contained in iron ore shipments from domestic mines plus imports and purchased scrap. However, demand from 1973 to 1977 was calculated directly from the components of U.S. supply as shown, disregarding changes in stocks.

The supply of finished steel in the rest of the world is approximately 75 percent of its production of raw steel, and supply of iron and

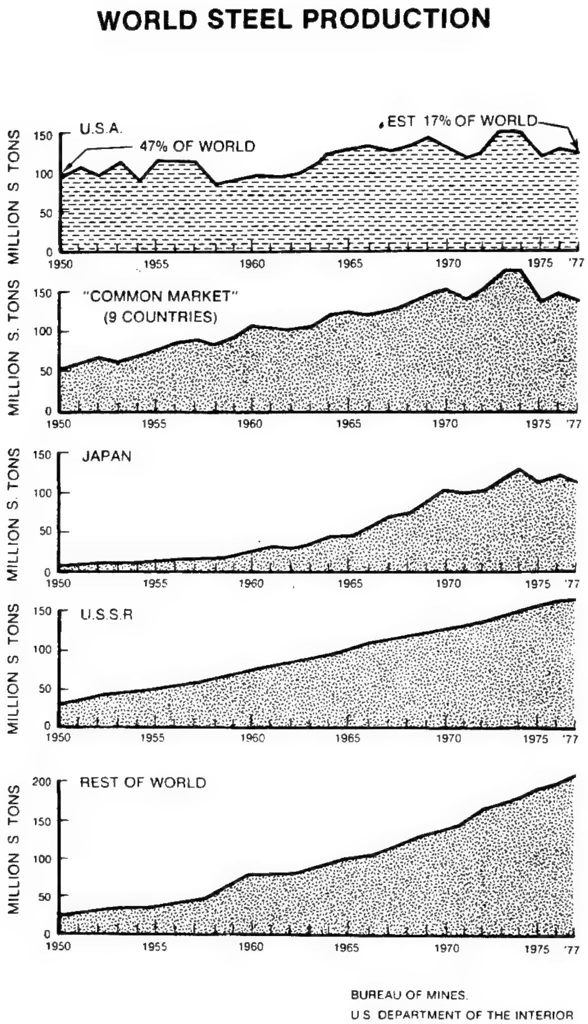

Figure 4.—Raw steel production, 1950–77, for the United States, the European Common Market, Japan, the U.S.S.R., and the rest of the world.

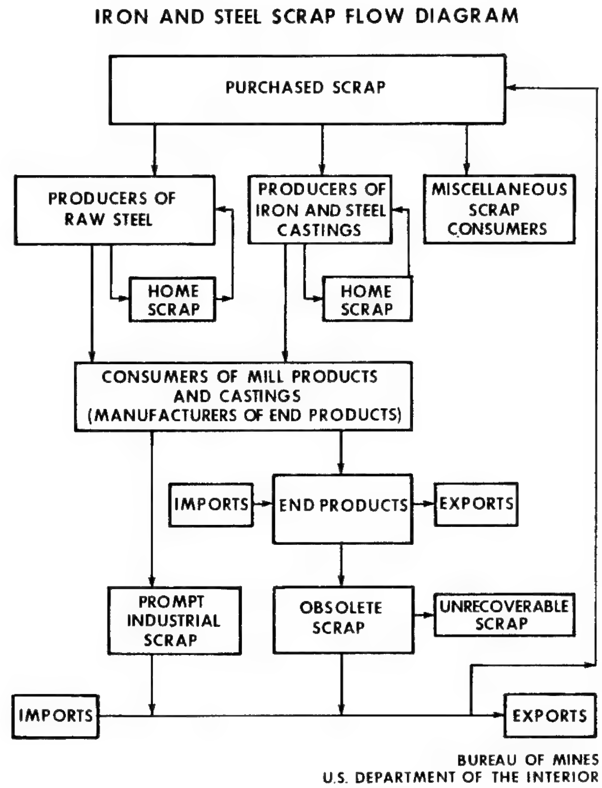

Figure 5.—Iron and steel scrap flow diagram.

steel castings is approximately 15 percent of supply of finished steel. Supplies of iron and steel products and foundry castings in the rest of the world are distributed in approximately the same proportions as the raw seel production data shown in the supply-demand relationship chart, figure 3. Raw steel production for 1950 through 1977 for the United States, the European Common Market, Japan, the U.S.S.R., and the rest of the world is shown in figure 4.

The United States has consumed an average of 122 million tons of finished iron and steel annually for the last decade, ranging from a low of 104 million tons in 1975 to more than 143 million tons in 1973. Because it is impractical to store iron and steel finished products for any extended period of time, it can be assumed that the rest of the world consumed the total of supply at about the rate it was produced.

There is virtually no part of our society that does not use iron and steel products in one way or another. In the 10-year period 1968–77, an average of 34 million tons per year was used in the transportation industries, 32 million tons in construction, 23 million tons in machinery, 8 million tons in cans and containers, 7 million tons in the oil and gas industries, and 7 million tons in appliances and equipment. The use of iron and steel by form and grade or mill product classification in 1977 is given in figures 6–8.

The broad end-use pattern is given in table 10 and shown for 1977 in figure 6. Approximately equal quantities of steel were used in the transportation and construction industries in the 10 years from 1968 to 1977, accounting for over 60 percent of the total. The pattern of iron and steel used for transportation, construction, and machinery follows closely the pattern of total use and the level of industrial activity. The use of steel in cans and containers and in appliances and equipment is not as closely related to industrial activity, although more steel is used in these categories when the

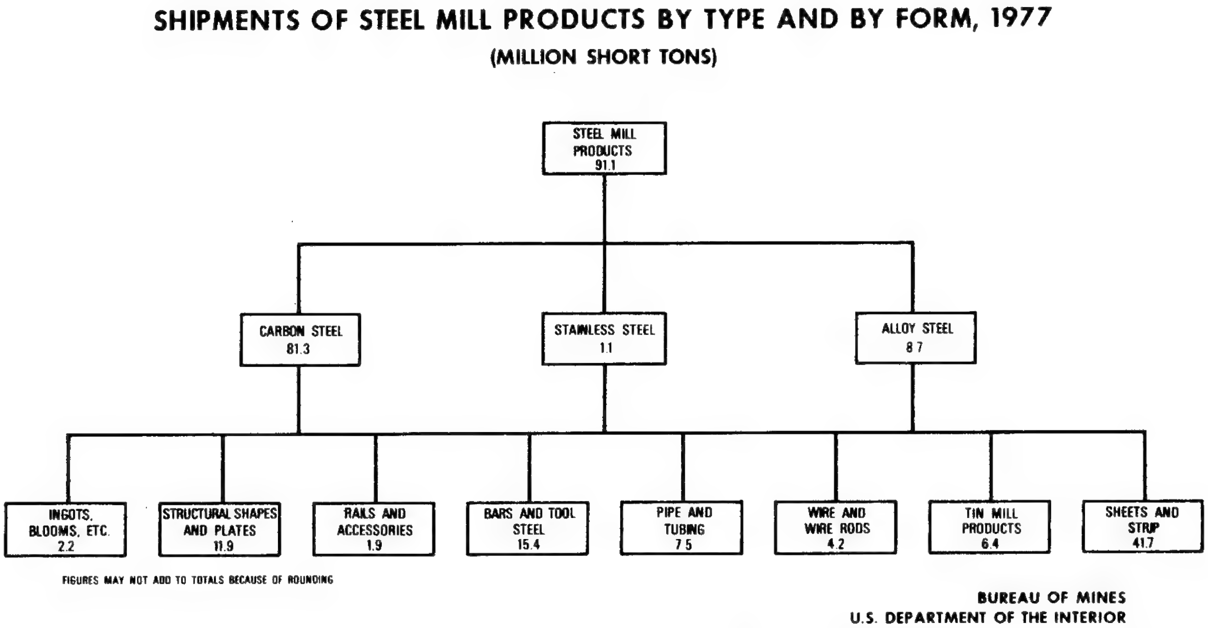

Figure 6.—Shipments of steel mill products by type and by form, 1977. Source: AISI Annual Statistical Report.

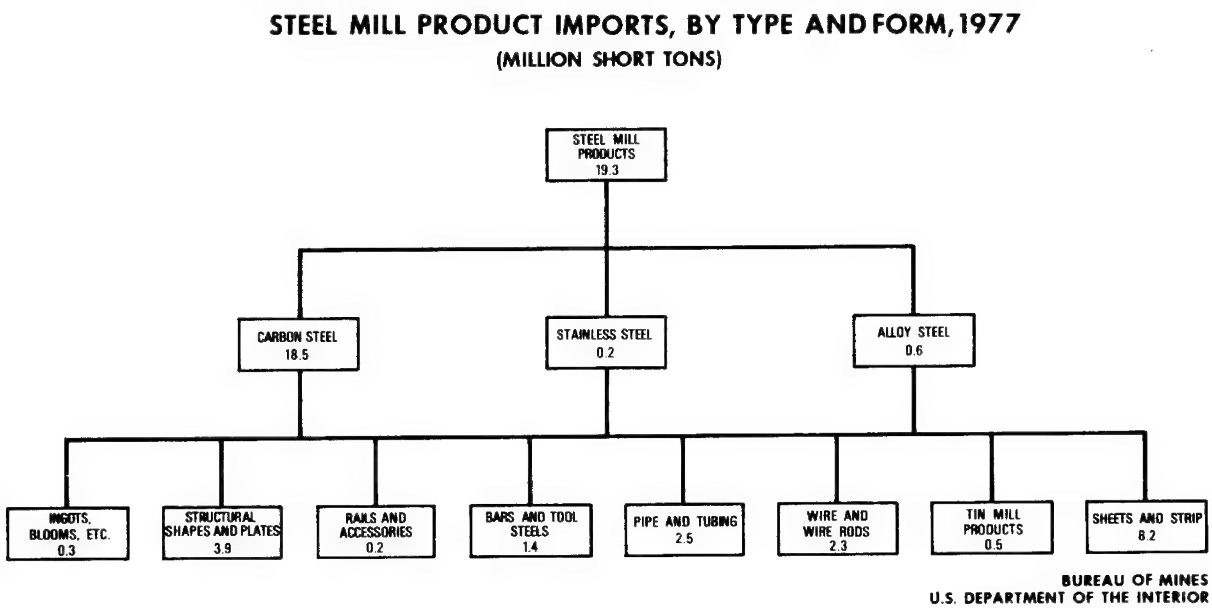

Figure 7.—Steel mill product imports by type and by form 1977. Source: AISI.

Nation is prosperous. The use of steel in the oil and gas industries was relatively constant at about 5 million tons per year from 1968 until 1972. The energy shortage in 1973 stimulated oil and gas exploration, new production wells were drilled, and increased amounts of steel were used by the oil and gas industries in 1973–1974 and 1977. The apparent use of steel in the "other" category fell after 1972 because of the changes in the method of computation as previously discussed.

Approximately 20 percent of the steel produced enters world trade. The European Economic Community (EEC) and Japan are the principal exporters, and sell steel throughout most of the world. In 1976, the EEC shipped 51 percent of the total they produced to other countries, but only 18 percent of the total entered trade with countries outside Western Europe. Japan was by far the largest single exporting country; 34 percent of its steel entered foreign trade. Eastern European coun-

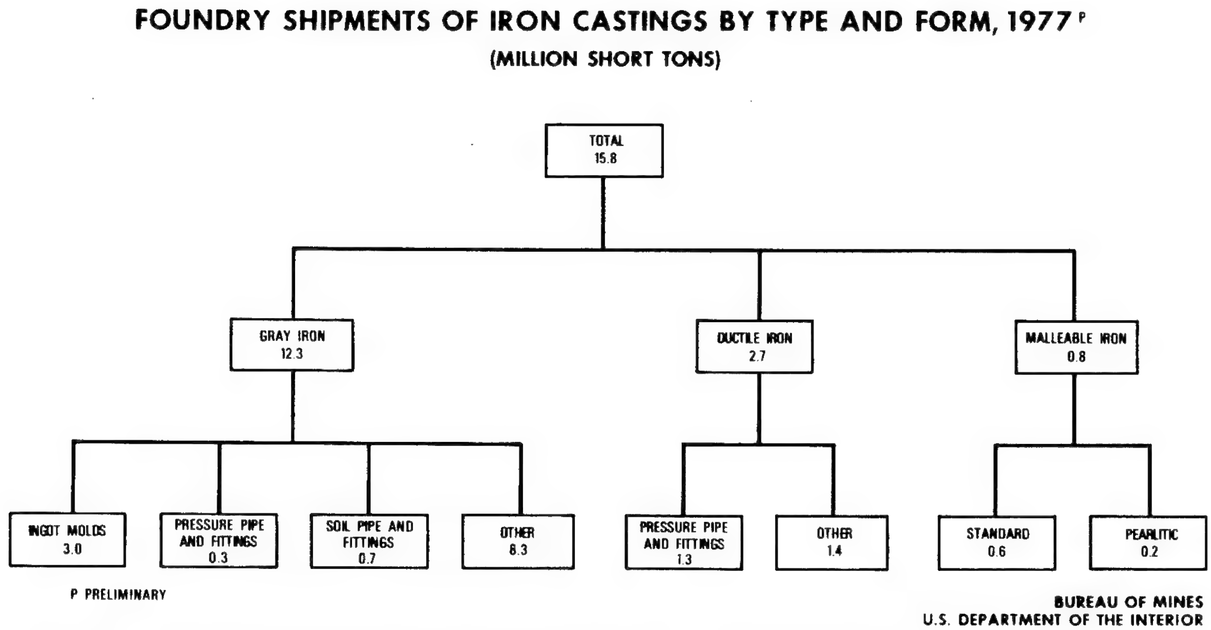

Figure 8.—Foundry shipments of iron castings by type and by form, 1977p. Source: U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census.

Table 11.—Exports of steel mill products, by destination, 1976

(Thousand short tons)

Principal exporters	Destination									
	North America	South America	Western Europe	U.S.S.R.	Other Eastern Europe	Asia	Africa	Oceania	Unallocated	Total[1]
EEC	3,943	1,026	35,902	4,488	2,588	4,144	3,168	121	----	55,379
Other Western Europe	506	180	6,137	653	907	602	424	7	----	9,416
U.S.S.R.	392	----	709	----	6,626	397	65	----	82	8,270
Other Eastern Europe	230	107	3,565	903	2,063	995	188	----	----	8,050
Japan	8,784	2,392	4,644	3,333	307	18,182	1,211	848	----	39,700
United States	1,020	385	522	10	32	591	110	18	----	2,688

[1] Data may not add to totals shown because of independent rounding.
Source: United Nations Economic Commission for Europe, Statistics of World Trade in Steel.

tries exported 26 percent of the steel they produced, the largest part of which went to Western European countries. The U.S.S.R. exported about 5 percent of its steel, mostly to Eastern European countries. World trade in steel mill products in 1976, as measured by exports and declared area of destination, is given in table 11.

In the developed countries, iron and steel products no longer valuable for their first end use are processed to scrap and returned as raw material to the steel mills and foundries. In the developing countries, however, particularly those countries without iron and steel industries, steel mill products may be salvaged when they have served the first purpose and reused in their original form, or after rerolling.

Substitutes

For some applications, there is no adequate substitute for steel's combination of mechanical and physical properties at comparable cost. For other applications, alloys of aluminum, copper, zinc, or magnesium may be substituted. In some cases, concrete, plastics, wood, fiberboard, plasterboard, or glass may be used in place of steel. Where high mechanical strength and ductility is required, as in machinery parts, railroad rails, and some structural members, no other material can replace steel except possibly alloys of titanium and other high-cost alloys that are used in aerospace and other specialized applications. Reinforced concrete is the major substitute for structural steel in buildings, and it is reinforced with steel bars. For vehicles, especially where weight saving is important, aluminum, magnesium, and plastics may substitute for some steel components. Aluminum, zinc, or magnesium castings can substitute for some iron or steel castings or stampings. As a sheathing material for buildings, aluminum and copper alloys, fiberboard, wood, plastics, masonry, and glass can take the

place of steel. In appliances and furniture, wood, plastics, and alloys of copper and aluminum may substitute for steel. Aluminum and copper alloys, and plastics may replace steel in cans and containers.

ECONOMIC FACTORS AND PROBLEMS

Capital Costs

In 1977 the steel industry of the United States had total assets of $35,414 million; stockholders' equity was $17,637 million. Property, plant, and equipment cost $41,366 million which had been depreciated, depleted, or amortized by $21,674 million, leaving net fixed assets of $19,692 million. At the end of 1977, the steel industry had 779,499 common stockholders and 36,167 preferred stockholders.

It is estimated that new steelmaking capacity, if installation was begun in 1977, would cost between $125 per annual ton of raw steel capacity for a minimill to $1,000 per ton for a new "greenfield" integrated steel plant. Costs are somewhat lower in Western Europe and considerably lower in Japan primarily because of lower labor costs. Pollution control equipment adds 5 to 15 percent to construction costs.

Investment in the iron and steel industry in the last decade has not been attractive because of its low earnings and lack of real potential for an adequate return on investments. The investment situation apparently changed in 1974, as steel company profits were relatively high. Deflation of the dollar had made the U.S. steel industry price competitive around the world, and the industry apparently was generating sufficient profit to take care of part of the cost of expanding capacity. However, earnings dropped during the 1975 recession and had not regained their 1974 levels by 1977.

The organizational pattern of the steel industry in the rest of the world has been marked by consolidation to take advantage of large-scale operations in the developed countries, and by proliferation of new iron and steelmaking facilities in the developing countries. Consolidation of the steel industry in the United Kingdom was achieved by nationalization with the formation of the British Steel Corp. In Western European countries, consolidation was done by merging individual steel producers under the sponsorship of the European Coal and Steel Community and the European Economic Community. In Japan consolidation was accomplished by merging private companies with

Table 12.—Summary of gross energy consumed to produce iron and steel, 1977

Item	Quantity consumed	10^{14}Btu	10^{10}kwhr
Steel industry:			
Coke	49,132,000 short tons	12.8	37.4
Coal for steam and other purposes (not coke)	3,329,000 short tons	.9	2.6
Purchased power	$54,024 \times 10^6$ kwhr	1.8	5.4
Fuel oil	$1,699 \times 10^6$ gal	2.6	7.6
Tar and pitch	181×10^6 gal	.3	.8
Liquid petroleum gas	39×10^6 gal	.04	.1
Natural gas	568×10^9 cu ft	5.7	16.6
Coke oven gas	776×10^9 cu ft	3.9	11.4
Subtotal		28.0	81.9
Foundries (purchased fuels and electrical energy)[1]		1.8	5.1
Total		29.8	87.0

[1] Estimated from 1971 data reported by Bureau of the Census, MC72(SR)-6.
Source: American Iron and Steel Institute, Annual Statistical Report, 1977, except as indicated in footnote 1.

strong encouragement by Government and international trading associations. Government ownership and control of steel production is common in the developing countries, and most protect their steel industries with high import tariffs.

Prices

A 24-year record of the *Iron Age* composite price for finished steel in actual and constant 1976 cents per pound is given in table 13. The high price in 1959 was the result of a 116-day labor strike resulting in a short supply of steel throughout most of the year. From 1962 to 1972, when the exchange rate favored imports, foreign competition held prices down. When the dollar was devalued, price controls prevented prices from rising, and when controls were removed in April 1974, the composite price immediately advanced and continued to rise through 1977.

Employment and Productivity

The steel industry had an average of 452,388 employees in 1977, and paid $9.2 billion in wages and salaries. Average payroll costs were $10.553 per hour. The Bureau of Labor Statistics index of output per man-hour in the steel industry rose from the base of 100 in 1967 to 118.2 in 1977. This index reflects the joint effect of influences such as changes in technology, capital investment per worker, utilization of capacity, layout and flow of material, worker and managerial skills, and labor-management relations.

Taxes and Tariffs

The statutory Federal corporate income tax rate of 48 percent on net income is applicable

Table 13.—Time-price relationship for steel

Year	Average annual Iron Age composite price, cents per pound	
	Actual prices	Based on constant 1976 cents
1954	4.716	10.567
1955	4.997	10.960
1956	5.358	11.393
1957	5.800	11.931
1958	6.060	12.270
1959	6.196	12.274
1960	6.196	12.068
1961	6.196	11.962
1962	6.196	11.746
1963	6.273	11.720
1964	6.368	11.714
1965	6.368	11.460
1966	6.399	11.150
1967	6.464	10.941
1968	6.601	10.692
1969	7.091	10.936
1970	7.650	11.200
1971	8.429	11.741
1972	8.999	12.035
1973	9.380	11.858
1974	11.141	12.801
1975	13.102	13.772
1976	14.213	14.213
1977	15.577	14.765

NOTE.—Finished steel composite is a weighted index of steel bars, shapes, plates, wire, rails, black pipe, hot and cold rolled sheets, and strips.

to the steel industry, and local and State taxes also apply in some localities. As in other industries, the steel industry is entitled to an investment tax credit, which amounted to 10 percent in 1977. The industry is permitted to amortize its investment in pollution control facilities in 5 years, and under the Tax Reform Act of 1976, can also apply 5 percent investment tax credit to this equipment. The industry is also permitted to recover its capital investment through depreciation. Capital invested in machinery and equipment before 1971 is depreciated over a period of 18 years. Investments after 1971 may be depreciated in a minimum of 14 ½ years.

Government taxes on the steel industries in foreign countries generally allow capital recovery in a shorter time than is required in the United States. The recovery period ranges from 1 year in the United Kingdom to 8, 9, and 10 years in France, West Germany, and Belgium, and 11 years in Japan. Japan allows a 25-percent investment tax credit in the first year which reduces the recoverable base cost. Luxembourg has an initial 18-percent allowance, equivalent to a 9-percent tax credit, and Sweden has an additional 30-percent allowance in the first year, but neither reduces the recoverable base cost. In addition, some foreign countries grant cash incentives for investment in new plant and antipollution equipment. France, for example, allows a 50-percent initial allowance for antipollution expenditures, and in Sweden 50 percent of the cost of qualifying pollution control facilities is subsidized by the national Government. West Germany allows a special 75-percent accelerated depreciation in the first 3 years for fixed industrial investment in West Berlin and 30- to 50-percent additional deduction for 5 years for pollution abatement facilities. Typical U.S. import duties for iron and steel products are shown in table 14.

Government Programs and Legislation

Import quotas on specialty steel (stainless and alloy tool steels) were instituted in mid-1976 and were continued through 1977. As a result of a White House task force organized late in 1977, a comprehensive program to aid the steel industry was instituted. The major feature of the program is a system of reference or "trigger" prices that apply to imported steel and that are based on costs of production of the most efficient foreign producers (currently the Japanese), including profit, transportation, and insurance. If steel is imported below the reference price, an antidumping investigation will begin immediately with resolution in 60 to 90 days. Other features of the program are aid for modernization, rationalizing environmental policies and procedures, community and labor assistance, and other general measures.

OPERATING AND PROCESSING FACTORS

Steel mills range in size from minimills, which melt scrap in electric arc furnaces and may not produce over 500,000 tons of raw steel per year, to fully integrated coke oven-blast furnace-basic oxygen furnace complexes, which produce as much as 10 million tons of steel per year. Rolling and shaping operations complement the melting facilities at all steel plants. These operations can be relatively simple, such as a bar mill for making reinforcing bars as the main product of a minimill, but at integrated plants, a wide range of hot- and cold-rolling mills, and treating lines are used to produce many different products.

The steelmaking portion of a typical integrated plant will contain units sized according to desired output. Adjoining space may be occupied by casting facilities, ore, coal, and scrap yards, and related preparation facilities. However, the bulk of a plant will be devoted to rolling mills and lines for processing ingots, slabs, and billets into such products as tubing, rod, beams, sheet, and strip. Because of large-size reductions and high linear speeds, rolling mills take up much space.

In expanding, the steel industry has tended to build within or adjacent to existing facilities, because the costs of building integrated plants

Table 14.—U.S. import duties[1]

TSUS No.	Material[2]	January 1, 1978	Statutory
608.40	Concrete reinforcing bars	7.5% ad valorem	20% ad valorem
608.45	Other bars	7% ad valorem	20% ad valorem
608.71	Wire rods, valued over 4¢ per pound	0.25¢ per pound	0.6¢ per pound
	Strip:		
609.02	Not over 0.01 inch thick	6% ad valorem	25% ad valorem
609.03	Over 0.01 inch, but not over 0.05 inch thick	8.5% ad valorem	25% ad valorem
609.04	Over 0.05 inch thick	9.5% ad valorem	25% ad valorem
	Round wire:		
609.40	Under 0.060 inch in diameter	8.5% ad valorem	25% ad valorem
609.41	0.060 inch or more in diameter	0.3¢ per pound	1.25¢ per pound
609.80	Angles, shapes, sections	0.1¢ per pound	0.2¢ per pound
610.20	Rails	0.05¢ per pound	0.1¢ per pound
	Pipes:		
610.30	Under 0.25 inch in outside diameter	0.875¢ per pound	1.75¢ per pound
610.31	0.25 inch to 0.375 inch	0.625¢ per pound	1.25¢ per pound
610.32	0.375 inch or more	0.3¢ per pound	0.75¢ per pound
610.56	Cast-iron pipes and tubes	10% ad valorem	25% ad valorem
607.15	Pig iron	Free	$1.125 per ton
608.02	Sponge iron	Free	$2.25 per ton
608.15	Ingots, blooms, billets, slabs, or sheet bars	6% ad valorem	20% ad valorem
608.25	Forgings	6% ad valorem	25% ad valorem
	Iron and steel waste and scrap:		
607.10	Tin plate waste or scrap	Free	Free
607.11	Other	Free	75¢ per ton

[1] Typical duties—not a complete listing.
[2] Other than alloy steel or iron.

at greenfield sites may be double those at existing plants. Construction at geeenfield sites in the last 15 years, with one exception (Bethlehem Steel Corp. at Burns Harbor, Ind.), has been restricted to minimills. The least expensive way to produce small quantities of steel is to melt scrap in an electric arc furnace. For large volume, economies of scale favor the fully integrated, blast furnace-basic oxygen furnace combination. The break-even point between the two types of plant varies with changing technology and costs of raw materials, energy, and capital.

Key raw materials for steelmaking are: Iron ore, coal (for coke and steam), fluxes (lime, limestone, dolomite, and fluorspar), ferroalloys and other alloy additives, scrap, refractories, and oxygen. The 1977 production of 125 million tons of raw steel required 121 million tons of iron ore and agglomerates, 73 million tons of coal, 69 million tons of home and purchased scrap, 28 million tons of fluxes, and 251 billion cubic feet of oxygen. Processing losses reduce steel mill shipments to about 70 percent of raw steel production. The proportion of steel cast continuously is expected to increase the ratio of shipments to raw steel, but to date, the shipment ratio has not been much affected by continuous casting because greater casting yields have been partly offset by higher product specifications.

The successful production of a variety of grades of steel in different shapes in a single plant requires a well-planned system of production controls. Modern facilities rely on computer-directed systems for scheduling and tracking materials flow and also for controlling the operation of furnaces and mills. The most profitable method of operation calls for as complete utilization of equipment as possible. The optimum of full utilization is rarely achieved, because the order pattern and backlog determine demands on equipment. Furnace and mill capacities within a given plant can be changed only in steps, so an imperfect balance between upstream and downstream units usually occurs. Decisions to install additional equipment are based on estimates of present and future markets subject to capital restrictions.

ENVIRONMENT AND POLLUTION CONTROL

Steel mills and foundries inherently present a wide range of environmental problems. In operation they produce solid waste, excess liquids, gases, and noise, all of which must be controlled to prevent pollution. Slags from the iron and steelmaking furnaces, flue dust, and mill scale are the principal solid wastes. Normally, ironmaking slags are readily salable for use as railroad ballast, aggregate for concrete, or for landfill. Steelmaking slags are often recycled within the plant to reclaim the iron and manganese they contain. Flue dust from the blast furnace operations and mill scale are principally iron oxides, and they are valuable additions in sintering plants. Flue dusts from the steel furnaces often contain other valuable constituents, but in many instances, these materials are impurities which prevent the dust from being returned to the system; therefore, disposal of the solid effluents from steelmaking furnaces often presents a problem.

Among the liquids, water, sulphuric and hydrochloric acid, oil and grease, all present environmental problems if not properly handled. The high temperature of water that has been used in steelmaking, as well as the impurities it contains, make it a pollutant. The average steel mill uses 34,000 gallons of water per ton of steel; less than 2,000 gallons per ton is needed for makeup if the water can be recirculated. Effluents from steel mills may contain zinc, manganese, lead, and nitrates, and they may be acidic or alkaline. Stringent standards imposed under the Federal Water Pollution Control Act make it costly to stay within effluent regulations; therefore, new steel plants are designed for zero water discharge, and the older mills recirculate as much water as possible.

Acid pickle liquors cannot be released in any locality where they might reach either surface or underground drainage systems. Sulphuric acid liquor has been neutralized and kept in holding ponds or injected in deep wells in strata below possible contamination of usable groundwater. Either process presents some risk of environmental damage. Because hydrochloric acid liquor can be regenerated and reused, most steel plants have changed, or are in the process of changing, to hydrochloric acid pickling.

Air pollution from steel plants presents one of the most difficult environmental control problems. Dust and fume are generally removed from the gaseous emissions from sinter plants, blast furnaces, and steel furnaces by cyclones, electrostatic precipitators, baghouses, and wet scrubbers. Coke ovens are the source of gaseous pollutants such as sulfur dioxide, tar vapors, and other organic compounds as well as particulate matter such as coal and coke dusts. Pollution control equipment can be added to existing coke ovens and is included in the construction of new equipment.

Noise has become a matter of concern in environmental control in the last few years. Safety regulations have established the noise level to which workers in steel mills can be exposed, and in some operations the workers must wear earplugs or some other device to reduce the noise to which they are exposed. Enclosures and installation of acoustical materials currently are the methods commonly used to control most noises. Researchers are experimenting with damping alloys to reduce the noise caused by mechanical operations and report significant success.

The U.S. steel industry had $2.9 billion invested in pollution control equipment at the end of 1974, and invested an additional $1.5 billion through 1977. To achieve all pollution control requirements by 1983 is estimated to cost an additional $8.1 to $10.1 billion. Thus, the total pollution control expenditures could reach $12.5 to $14.5 billion by 1983. Several studies have indicated that operating costs for pollution equipment by 1983 would add 8 to 10 percent to the operating costs of the steel industry.

An Organization for Economic Cooperation and Development (OECD) study (*24*) of emission control costs in the iron and steel industry indicated that the present level of pollution control costs varies considerably from country to country. Since present costs are small compared with average product price, the cost differences have not created any significant trade effects. However, costs estimated for stricter pollution controls (estimated at $40 to $50 per ton of output) will constitute a significant part of production costs. Thus, the time schedule under which countries institute stricter controls could influence trade flows.

OCCUPATIONAL FACTORS AND PROBLEMS

Ironmaking and steelmaking have long been recognized as presenting occupational hazards. For example, employees work with very hot liquid metal, explosive gases, and heavy materials and equipment. They are exposed to possible splashes or spills of hot metal, moving machinery, a wide range of illumination, and a generally noisy environment. Industry-related illnesses have been reported, but most have dealt with coking plant operations or were concerned with dermatologic disorders.

The iron and steel industries are covered by the Federal Occupational Safety and Health Act (OSHA) of 1970, which took effect April 28, 1971. Under the Act, an employer has: (1) The general duty to furnish each of its employees employment and places of employment free from recognized hazards causing, or likely to cause, death or serious physical harm; and (2) the specific duty of complying with safety and health standards promulgatqd under the Act. Furthermore, employers are required to maintain accurate records of work-related deaths, injuries, and illnesses, and to make periodic reports to Federal authorities.

In general, safety and health standards and regulations under the Act, as applied to the iron and steel industry, differ little from those under which the industry has been operating for the last 20 years. Reports of occupational injuries and illnesses by industry in 1972, published in U.S. Department of Labor, Bu-

reau of Labor Statistics Bulletin 1830 in 1974, show that the blast furnace and basic steel industry had 16.7 recordable cases per 100 full-time workers and that iron and steel foundries had 31.6 cases per 100 workers. The injury rate of the blast furnace and basic steel industry was 12 percent higher than all manufacturers, but 18 percent lower than all primary metal industries. The incidence of injuries in the iron foundries was 112 percent higher than that of all manufacturing, and 55 percent higher than that of all primary metal industries. Work-related illnesses reported in both basic steel and foundry industries differed little from these reported for all manufacturing and all primary metal industries. According to available reports, slips, falls, and lifting have caused most ferrous foundry accidents.

The effects of iron on the human body are given in a report of the Subcommittee on Iron, Committee on Medical and Biologic Effects of Environmental Pollutants, National Research Council (*31*). Iron in the human body is largely in the form of hemoglobin within the red blood cells, which serve to transport oxygen. Iron deficiency in the United States and worldwide is a major health problem in children, in women during their reproductive years, and particularly in pregnant women. Nutritional iron deficiency in adult men is rare.

Acute iron poisoning from ingested iron is unlikely to be encountered from any source other than medicinal iron, usually as a result of accidental ingestion of iron pills by very young children. No known natural or dietary sources are likely to cause acute iron toxicity. Chronic dietary iron overload rarely if ever occurs. Occupational exposure to iron oxide by inhalation has been found to produce pulmonary siderosis, a benign disorder. Suspicions of an occupational hazard of lung cancer associated with hematite mining have not been conclusively proved. In those cases in which an increased risk has been suspected, the probable cause was the presence of radon in the work environment.

OUTLOOK

Demand

The demand for steel mill products and iron and steel foundry products (iron and steel demand) in the United States in the year 2000 is forecast to range from a low of 160 million tons to a high of 211 million tons, with the most probable demand at 188 million tons. The probable demand indicates an average annual growth rate of 1.6 percent based on a trend value for 1976 of 127.9 million tons.

In a mature economy, such as that of the United States, it is believed that iron and steel demand closely follows population. The demand forecasts were therefore based on a curvilinear regression of steel demand (steel mill shipments plus imports) on population, as shown in figure 9. The relatively rapid rise in steel usage at the beginning of the 20th century, caused by the advent of the automobile, was eliminated by beginning the regression line with 1915 data, establishing a 62-year trend. The demand projections for 2000 were based on Bureau of the Census population projections Series I–III. Although the demand data used in the regression included exports, the projections were made on the basis of domestic consumption excluding exports. Exports were assumed to remain at the average of 3 percent of steel demand (including exports) established over the past few years. Foundry shipments estimated at 16 percent of steel mill demand, based on past experience, were included in the forecasts of total iron and steel demand.

Iron and steel demand for the rest of the world in 2000 is forecast to range from 1,040 million tons to 1,450 million tons, with the most probable demand at 1,170 million tons, indicating a 3.1 percent average annual growth rate based on a 1976 trend value of 563.6 million tons.

The forecast for the rest of the world was based on a projection of raw steel production, taking into account forecasts by the United Nations and other international organizations and modified by recent curtailment or postponement of expansion plans throughout the world. Raw steel production was then converted to finished steel on the basis of 75 percent yield, and imports by the United States were subtracted to give an estimate of steel demand. Foundry product demand was estimated at 15 percent of steel demand on the basis of past experience and added to steel demand to give an estimate of total iron and steel demand.

The growth rates shown are higher than that for the United States because of the inclusion in the rest of the world of developing countries in which the per capita consumption of steel is increasing.

A summary of forecasts of iron and steel demand for the United States and the rest of the world is given in table 15. Table 16 shows statistical projections and forecasts of domestic iron and steel demand by end use. The statistical projections are derived from regression analyses based on forecasts of Federal Reserve

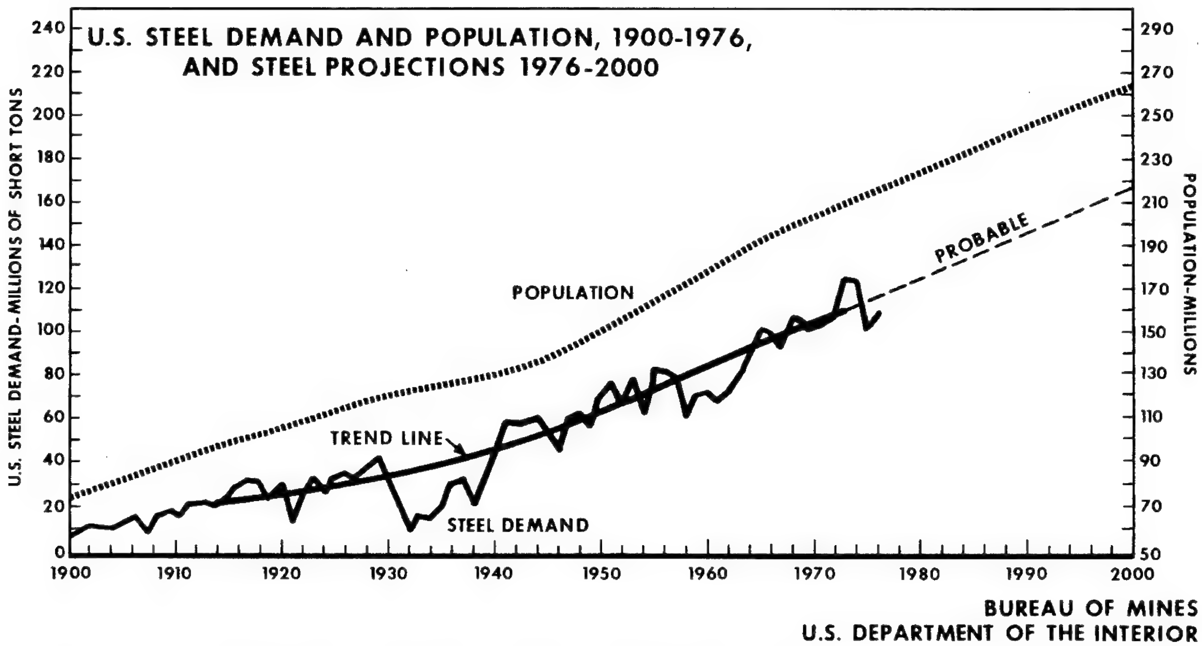

Figure 9.—U.S. steel demand and population, 1900–76, and projections, 1976–2000. Probable steel demand is 131.5 million tons in 1985 and 166.6 million tons in 2000. Population projection is based on U.S. Bureau of the Census Series II figures.

Board indices or gross private domestic investment. In some cases the correlation with these indices was poor, and in general the projections tend to be high compared with the contingency forecasts. The contingency forecasts for the year 2000 were based on the forecasts for U.S. iron and steel demand given in table 15 with proportionate division into the various end uses based on historical trends as modified by judgment.

Transportation.—The statistical projection of 65 million tons in 2000 is based on the Federal Reserve Board index for motor vehicles and parts. It falls above the contingency forecast range probably because it does not take into account the expected smaller sizes of automobiles in the future. Use of iron and steel in the transportation industry is forecast to range from a low of 49 million tons to a high of 58 million tons. The low forecast anticipates the use of smaller automobiles, increased use of substitute materials such as aluminum and plastics, and use of higher strength steels. The high forecast results from anticipated use of more steel in the rebuilding of the railroad system, greater use of steel in mass transit and marine construction, and other uses such as in air-pollution control equipment for transportation units. The probable forecast of 56 million tons gives greater weight to the last considerations.

Construction.—The statistical projection of 82.3 million tons in 2000 is based on the gross private domestic investment index. This value lies above the contingency forecast range, possibly because the apportionment of private domestic investment in the future may vary from that in the past. Use of iron and steel in the construction industry is forecast to range from 49 to 64 million tons. The low figure assumes greater use of substitute materials and use of high-strength steels, and the high forecast is based on anticipated greater use of steel in construction because of technological changes, rebuilding of cities, and increased recreational and industrial construction, as well as greater use of steel in domestic housing units. The assumption that the construction industry will require relatively more iron and steel than the overall economy leads to a probable forecast of 60 million tons.

Machinery.—The statistical projection of 39 million tons in 2000 is based on the Federal Reserve Board index for major electrical equipment and parts and falls within the contingency forecast range. Use of iron and steel in machinery will probably grow at a slower rate than the overall economy because of the tendency to use higher strength steels and to substitute ductile cast iron for gray iron. Accordingly, the probable demand of 32 million tons favors the low end of the forecast range. On the other hand,

Table 15.—Summary of forecasts of U.S. and rest of world iron and steel demand, 1976-2000

(Million short tons)

	1976	2000 forecast range		Probable		Probable average annual growth rate 1976-2000, percent [1]
		Low	High	1985	2000	
United States:						
Total	117.8	160	211	148	188	1.6
Cumulative	----	3,440	4,020	1,250	3,770	----
Rest of world:						
Total	520.9	1,040	1,450	742	1,170	3.1
Cumulative	----	18,900	22,900	5,930	20,300	----
World:						
Total [2]	638.7	1,200	1,660	890	1,350	2.8
Cumulative	----	22,300	27,000	7,180	23,900	----

[1] Based on trend values for 1976.
[2] Data may not add to totals shown because of independent rounding.

Table 16.—Projections and forecasts for U.S. iron and steel demand by end use, 1976 and 2000

(Million short tons)

End use	1976	2000			
		Statistical projections [1]	Contingency forecasts for U.S.		
			Forecast range		Probable
			Low	High	
Transportation	38.0	65.0	49	58	56
Construction	30.3	82.3	49	64	60
Machinery	23.7	39.0	29	40	32
Cans and containers	8.0	14.5*	11	13	12
Oil and gas industries	6.8	10.6*	6	11	7
Appliances and equipment	6.5	15.8	10	15	12
Other	4.5	41.7*	6	10	9
Total	117.8		160	211	188

[1] Statistical projections are derived from regression analysis based on historical time series data, and forecasts of economic indicators such as gross national product (GNP), Federal Reserve Board (FRB) index, etc. Projection equations with a coefficient of determination (R-squared) less than 0.70 are indicated by an asterisk (*).

more mechanization of industry and the need for pollution control equipment could lead to the high forecast of 40 million tons.

Cans and Containers.—The statistical projection of 14.5 million tons in 2000 is based on gross private domestic investment; however, the R^2 value is 0.49 indicating poor correlation. Little change is anticipated in the per capita use of steel in cans and containers, leading to a probable forecast of 12 million tons. The low forecast of 11 million tons could result from substitution, and the high forecast of 13 million tons could result from the recovery by steel of markets lost to such substitutes as aluminum and plastics. Iron foundry products are not used in cans and containers.

Oil and Gas Industries.—The statistical projection of 10.6 million tons in 2000 is based on the Federal Reserve Board index for petroleum products and falls within the contingency forecast range even though the correlation is poor. The use of iron and steel in the oil and gas industries is expected to range from 6 to 11 million tons. The use is expected to increase rapidly for the next 10 to 12 years as the result of more exploration to find new resources. Both exploration and production wells will be at greater depths. The increased use is expected to taper off, however, as other sources of energy are developed and areas geologically favorable to the existence of oil or gas are explored. The probable forecast of 7 million tons is based on these contingencies. The high forecast could result from a restructuring of the oil and gas industry to use coal instead of petroleum as a raw material. In this case, new processing facilities and pipelines would be needed to accommodate the change.

Appliances and Equipment.—The statistical projection of 15.8 million tons in 2000 is based on gross private domestic investment and lies slightly above the contingency forecast range, probably because of changes in the apportionment of private domestic investment in the future. Demand for iron and steel in appliances and equipment will probably parallel the overall demand, leading to a probable forecast of 12 million tons. The low of 10 million tons could arise from increased use of substitutes and the high from continued increase in demand for household appliances.

Other.—The statistical projection of 41.7 million tons in 2000 is based on the Federal Reserve Board index for metalworking ma-

chinery and lies well above the contingency forecast range; however, the correlation is extremely poor as indicated by a R^2 value of 0.17. Use of iron and steel in this category covers many small applications, most of which are expected to increase with the standard of living and increased automation. Steel used in applications not yet developed is expected to increase substantially above the national average, leading to a forecast range of 6 to 10 million tons with the probable forecast at 9 million tons.

Exports.—Iron and steel for exports are not included in the forecasts shown in table 15. In the period 1968–77, exports have ranged from a low of 2.0 million tons in 1977 to a high of 7.1 million tons in 1970. If the United States improves its competitive position with respect to steel producers in Europe and Japan, exports should slowly increase. U.S. exports of steel mill products in 2000 are forecast to range between 2 and 8 million tons with a probable figure of 5 million tons.

Supply

Assuming an adequate supply of raw materials and energy, the domestic supply of iron and steel is dependent upon the capacity of the U.S. steel mills and foundries and to some extent on the availability of iron and steel products on the world market. Imports of steel mill products have become a significant part of U.S. supply providing from 12 to 18 percent of the total since 1968.

Iron and steel foundries are either part of a large manufacturing enterprise (*captive* foundries) or supply castings for the general market (*jobbing* foundries). In either case, the tendency in the past has been to add capacity, either by expansion or by building new foundries as required by demand. It can be assumed that domestic demand for foundry products to the year 2000 will be met with little difficulty by supply from domestic plants now in existence or that will be built in the normal expansion of the industrial complex.

Domestic raw steelmaking capacity is projected to reach 163 million tons per year in 1980. An average of about 1 million tons of annual steelmaking capacity must be added each year after 1977 to reach this figure. By the year 2000, a raw steel equivalent of 231 million tons will be needed to meet the probable demand forecast of 167 million tons of steel mill products. If no steel is imported, a maximum capacity of 257 million tons per year would be needed, and between 1980 and 2000, an average of 4.7 million tons per year of annual capacity would have to be added. Allowing for a probable 15 percent of steel supply from imports, 218 million tons, or an addition of 2.8 million tons per year annual capacity, would be needed. If imports reach 25 percent of supply, the required domestic raw steel capacity would be 193 million tons per year, requiring an annual capacity increase of 1.5 million tons. If the ratio of finished steel to raw steel exceeds 0.72 in 2000 because of improved technology, the required raw steel capacities will be less than the preceding figures.

The amount of steel imported into the United States depends on several economic and political factors, including the relative cost of steel production in the United States and abroad, whether a worldwide shortage or oversupply of steel exists, the imposition of tariffs, quotas or "antidumping" restrictions by the Government, or voluntary restraint agreements or orderly marketing agreements between the United States and other countries. Under normal conditions, and when there is a worldwide oversupply, imported steel is priced somewhat below domestic steel, but in times of shortage this may be reversed. In times of world oversupply, steel may be imported at a loss to the exporting producers to maintain operation of their plants. Government controls or agreements between governments have in the past been instituted when it is determined that excess imports are damaging the domestic industry.

The probable demand in the rest of the world for finished steel in 2000 is 1,013 million tons. This is equivalent to raw steel demand of about 1,350 million tons which would require a nominal capacity of 1,500 million tons per year. To reach this figure, 31 million tons of raw steel capacity must be added to the rest of the world each year from 1980 to 2000. If insufficient new capacity is added to meet this demand, consumption of steel could be restricted by supply.

Possible Supply-Demand Changes

U.S. raw steel equivalent demand (including exports) was 148.3 million tons in 1976 and 157.9 million tons in 1977. Domestic raw steel production was 128.0 million tons in 1976 and 124.7 million tons in 1977. The balance of U.S. demand was supplied by imports of steel mill products. Raw steel equivalent demand in 2000 is forecast at 231 million tons, of which 203 million tons is expected to be supplied by domestic production and the balance by imports.

Table 17.—Comparison of U.S. raw steel equivalent demand and raw steel production, 1957-77, 1985, and 2000

(Million short tons)

Year	U.S. raw steel equivalent demand [1]		U.S. raw steel production
1957	115.9		112.7
1958	88.1		85.3
1959	105.5		93.4
1960	106.5		99.3
1961	99.1		98.0
1962	106.8		98.3
1963	115.8		109.3
1964	130.7		127.1
1965	147.4		131.5
1966	144.1		134.1
1967	136.4		127.2
1968	157.0		131.5
1969	154.3		141.3
1970	149.0		131.5
1971	150.6		120.4
1972	156.6		133.2
1973	181.0		150.8
1974	179.4		145.7
1975	131.5		116.6
1976	148.3		128.0
1977[e]	157.9		124.7
1985	[2] 188	[3] 164	[e] 160
2000	[2] 231	[3] 198	[e] 197

[e] Estimated.
[p] Preliminary.
[1] Shipments plus imports; 1 ton raw steel equivalent to 0.70 tons finished steel, 1957-85; 0.72 tons finished steel, 2000.
[2] Probable forecast.
[3] 20-year trend.

Prior to 1959, the United States was a net exporter of steel. Since then the United States has become a net importer of steel, with net imports (imports minus exports) ranging from 6.3 to 17.3 million tons in the past 10 years, averaging 12.0 million tons per year. The United States is expected to remain a net importer of steel, as influenced by considerations discussed in the previous section.

Japan and Western Europe have been the largest suppliers of imported steel to the United States. This pattern may change as developing countries become producers and exporters of steel. Steel production in these countries has increased over sevenfold from 1957 to 1977, and was 7.3 percent of world production in 1977. The oil-rich countries of the Middle East, having large supplies of natural gas, may become important producers and exporters of direct-reduced iron. Canada and Australia, with adequate supplies of coal and iron ore, may become major exporters of iron and steel. At the same time, Japan and Western Europe will probably become less important because of increasing labor and other costs, diminishing availability of raw materials, and pollution control requirements.

Possible Technological Advances

Replacement of present processes with new technology will be determined by such factors as the comparative economic advantages of the processes, the availability of capital, the need for new capacity, the availability of particular types of raw materials and energy, and the influence of Government regulations. Installations in the near future will incorporate improvements in present technology which is based on the coke oven-blast furnace-BOF system of steelmaking. Improvements will include more extensive use of instrumentation and computer controls in the steelmaking and finishing processes, and of continuous casting and rolling. Further use of direct-reduced iron in the United States will depend on development of improved solid-fuel processes or gasification of solid fuels to allow gas-based processes to be used.

Further in the future, some form of continuous steelmaking may be adopted. Such systems have been developed in the experimental or pilot stage in several countries and involve methods of continuously refining pig iron into steel as a replacement for the batch BOF process, or continuous melting of scrap or direct-reduced iron in the electric arc furnace. Still further in the future are methods for direct production of liquid steel from iron ore or concentrates, completely bypassing the coke oven-blast furnace-BOF system. One such experimental system utilizes plasma heating with hydrogen and natural gas as reductants. These continuous-steelmaking processes can be combined with continuous casting and rolling to give a truly continuous process from iron ore to finished steel products.

The use of nuclear energy in steelmaking has been studied in the United States, Europe, and Japan. In each case the proposed system involves a very high temperature reactor (VHTR) in which nuclear energy in the form of heat will be used to produce reducing gases from solid fuel. These gases would then be used to produce direct-reduced iron, which would be melted in an electric arc furnace to produce steel.

New steels for special applications will be developed. Examples are steel for use at low temperatures in high pressure pipelines; high strength, corrosion-resistant steels for marine use, including oil and gas drilling platforms and desalinization equipment; and steels for various nuclear energy applications. The trend toward use of lower levels of alloying element in steels and in the production of cleaner steels with improved ductility at higher strengths will continue.

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